United States Department of Agriculture

Economic Research Service

Economic Research Report Number 162

February 2014

Genetically Engineered Crops in the United States

Jorge Fernandez-Cornejo, Seth Wechsler, Mike Livingston, and Lorraine Mitchell



ED_005172C_00001883-00001

United States Department of Agriculture

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Recommended citation format for this publication:

Fernandez-Cornejo, Jorge, Seth Wechsler, Mike Livingston, and Lorraine Mitchell. *Genetically Engineered Crops in the United States*, ERR-162 U.S. Department of Agriculture, Economic Research Service, February 2014.

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Abstract

More than 15 years after their first successful commercial introduction in the United States, genetically engineered (GE) seeds have been widely adopted by U.S. corn, soybean, and cotton farmers. Still, some questions persist regarding the potential benefits and risks of GE crops. The report finds that, although the pace of research and development (measured by the number of USDA-approved field tests) peaked in 2002, other measures show that biotech firms continue to develop new GE seed varieties at a rapid pace. Also, U.S. farmers continue to adopt GE seeds at a robust rate, and seed varieties with multiple (stacked) traits have increased at a very rapid rate. Insecticide use has decreased with the adoption of insect-resistant crops, and herbicide-tolerant crops have enabled the substitution of glyphosate for more toxic and persistent herbicides. However, overreliance on glyphosate and a reduction in the diversity of weed management practices have contributed to the evolution of glyphosate resistance in some weed species.

Keywords: Genetically engineered crops, agricultural biotechnology, seed industry, research and development, adoption, crop yields, pesticide use, corn, soybeans, cotton

Acknowledgments

The authors wish to thank ERS colleagues Paul Heisey, Marca Weinberg, and Utpal Vasavada for their helpful comments provided on earlier drafts of this report. We also thank Michael Schechtman, USDA's Agricultural Research Service, Office of Pest Management Policy; Neil Hoffman, USDA's Animal and Plant Health Inspection Service; Mark Petry, USDA's Foreign Agricultural Service; George Frisvold, University of Arizona; and Corinne Alexander, Purdue University. We also thank Dale Simms for editorial assistance and Cynthia A. Ray for graphics and layout, both ERS.

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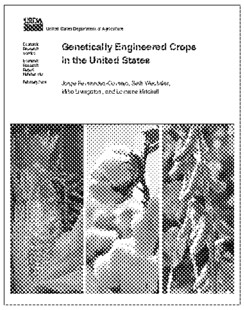

Find the full report at *www.ers.usda.gov/publications/err-economic-research-report/err162.aspx*

Genetically Engineered Crops in the United States

Jorge Fernandez-Cornejo, Seth Wechsler, Mike Livingston, and Lorraine Mitchell

What Is the Issue?

Genetically engineered (GE) varieties with pest management traits became commercially available for major crops in 1996. More than 15 years later, adoption of these varieties by U.S. farmers is widespread and U.S. consumers eat many products derived from GE crops—including cornmeal, oils, and sugars—largely unaware that these products were derived from GE crops. Despite the rapid increase in the adoption of corn, soybean, and cotton GE varieties by U.S. farmers, questions persist regarding their economic and environmental impacts, the evolution of weed resistance, and consumer acceptance.

What Did the Study Find?

This report examines issues related to three major stakeholders in agricultural biotechnology: GE seed suppliers and technology providers (biotech firms), farmers, and consumers.

GE seed suppliers/technology providers. The number of field releases for testing of GE varieties approved by USDA's Animal and Plant Health Inspection Service (APHIS) is an important measure of research and development (R&D) activities in agricultural biotechnology. The number of releases grew from 4 in 1985 to 1,194 in 2002 and averaged around 800 per year thereafter. However, while the number of releases peaked in 2002, other measures of research and development activity—the number of sites per release and the number of gene constructs (ways that the gene of interest is packaged together with other elements)—have increased very rapidly since 2005. Also, releases of GE varieties with agronomic properties (like drought resistance) jumped from 1,043 in 2005 to 5,190 in 2013.

As of September 2013, about 7,800 releases were approved for GE corn, more than 2,200 for GE soybeans, more than 1,100 for GE cotton, and about 900 for GE potatoes. Releases were approved for GE varieties with herbicide tolerance (6,772 releases), insect resistance (4,809), product quality such as flavor or nutrition (4,896), agronomic properties like drought resistance (5,190), and virus/fungal resistance (2,616). The institutions with the most authorized field releases include Monsanto with 6,782, Pioneer/DuPont with 1,405, Syngenta with 565, and USDA's Agricultural Research Service with 370. As of September 2013, APHIS had received 145 petitions for deregulation (allowing GE seeds to be sold) and had approved 96 petitions: 30 for corn; 15 for cotton; 11 for tomatoes; 12 for soybeans; 8 for rapeseed/canola; 5 for potatoes; 3 for sugarbeets; 2 each for papaya, rice, and squash; and 1 each for alfalfa, plum, rose, tobacco, flax, and chicory.

Farmers. Three crops (corn, cotton, and soybeans) make up the bulk of the acres planted to GE crops. U.S. farmers planted about 169 million acres of these GE crops in 2013, or about half of total land used to grow crops. Herbicide-tolerant (HT) crops have traits that allow them to tolerate more effective herbicides, such as glyphosate, helping adopters control pervasive weeds more effectively. U.S. farmers used HT soybeans on 93 percent of all planted soybean acres in 2013.

ERS is a primary source of economic research and analysis from the U.S. Department of Agriculture, providing timely information on economic and policy issues related to agriculture, food, the environment, and rural America.

HT corn accounted for 85 percent of corn acreage in 2013, and HT cotton constituted 82 percent of cotton acreage. Farmers planted insect-resistant (Bt) cotton to control pests such as tobacco budworm, cotton bollworm, and pink bollworm on 75 percent of U.S. acreage in 2013. Bt corn—which controls the European corn borer, the corn rootworm, and the corn earworm—was planted on 76 percent of corn acres in 2013.

The adoption of Bt crops increases ***yields*** by mitigating yield losses from insects. However, empirical evidence regarding the effect of HT crops on yields is mixed. Generally, stacked seeds (seeds with more than one GE trait) tend to have higher yields than conventional seeds or than seeds with only one GE trait. GE corn with stacked traits grew from 1 percent of corn acres in 2000 to 71 percent in 2013. Stacked seed varieties also accounted for 67 percent of cotton acres in 2013.

Planting Bt cotton and Bt corn seed is associated with higher ***net returns*** when pest pressure is high. The extent to which HT adoption affects net returns is mixed and depends primarily on how much weed control costs are reduced and seed costs are increased. HT soybean adoption is associated with an increase in total household income because HT soybeans require less management and enable farmers to generate income via off-farm activities or by expanding their operations.

Farmers generally use less ***insecticide*** when they plant Bt corn and Bt cotton. Corn insecticide use by both GE seed adopters and nonadopters has decreased—only 9 percent of all U.S. corn farmers used insecticides in 2010. Insecticide use on corn farms declined from 0.21 pound per planted acre in 1995 to 0.02 pound in 2010. This is consistent with the steady decline in European corn borer populations over the last decade that has been shown to be a direct result of Bt adoption. The establishment of minimum refuge requirements (planting sufficient acres of the non-Bt crop near the Bt crop) has helped delay the evolution of Bt resistance. However, there are some indications that insect resistance is developing to some Bt traits in some areas.

The adoption of HT crops has enabled farmers to substitute glyphosate for more toxic and persistent ***herbicides***. However, an overreliance on glyphosate and a reduction in the diversity of weed management practices adopted by crop producers have contributed to the evolution of glyphosate resistance in 14 weed species and biotypes in the United States. Best management practices (BMPs) to control weeds may help delay the evolution of resistance and sustain the efficacy of HT crops. BMPs include applying multiple herbicides with different modes of action, rotating crops, planting weed-free seed, scouting fields routinely, cleaning equipment to reduce the transmission of weeds to other fields, and maintaining field borders.

The ***price*** of GE soybean and corn seeds grew by about 50 percent in real terms (adjusted for inflation) between 2001 and 2010. The price of GE cotton seed grew even faster. The yield advantage of Bt corn and Bt cotton over conventional seed has become larger in recent years as new Bt traits have been incorporated and stacked traits have become available. Planting Bt cotton and Bt corn continues to be more profitable, as measured by net returns, than planting conventional seeds.

Consumers. Consumer acceptance of foods with GE ingredients varies with product characteristics, geography, and the information that consumers are exposed to. Most studies in industrialized nations find that consumers are willing to pay a premium for foods that don't contain GE ingredients. However, studies in developing countries yield more mixed results. Some studies, including some with a focus on GE ingredients with positive enhancements (such as nutrition), find consumers to be willing to try GE foods and even to pay a premium for them, while others find a willingness to pay a premium for non-GE foods. Most studies have shown that willingness-to-pay for non-GE foods is higher in the EU, where some retailers have policies limiting the use of GE ingredients. Non-GE foods are available in the United States, but there is evidence that such foods represent a small share of retail food markets.

How Was the Study Conducted?

This report updates the ERS report titled *The First Decade of Genetically Engineered Crops in the United States*. To consider biotech seed firms, we use information from the literature and analyze USDA data on field testing approvals by APHIS for new GE varieties. To study farmers' use of GE crops, we analyze USDA farm surveys, particularly the Agricultural Resource Management Survey (ARMS), and summarize the literature. To understand consumers' perspectives, we summarize surveys of consumers' attitudes from the literature.

Genetically Engineered Crops in the United States

Introduction

Genetic engineering is a key component of modern agricultural biotechnology.[1] The first genetically engineered (GE) plant, a tomato, was developed in 1982 (USDA/ARS, 2012). By 1985, the USDA had approved four releases of GE organisms for field testing. Commercial use of major GE crops began in 1996.[2]

Genetically engineered crop traits have been classified into one of three generations (Fernandez-Cornejo, 2004). The first generation features enhanced input traits such as herbicide tolerance, resistance to insects, and resistance to environmental stress (like drought). The second features value-added output traits such as nutrient-enhanced seeds for feed. The third generation of GE crops would include traits to allow production of pharmaceuticals and products beyond traditional food and fiber.

While the first GE crop approved by USDA's Animal and Plant Health Inspection Service (APHIS) and commercialized in 1994 was a crop with a strictly second-generation trait (FlavrSavr tomato), most GE crops planted in the United States have first-generation traits. All three generations of GE crop traits are in various stages of research and development.[3]

Most U.S. acres planted to GE crops have traits that provide herbicide tolerance (HT) and/or insect resistance. These seeds became commercially available in 1996. HT crops are able to tolerate certain highly effective herbicides, such as glyphosate, allowing adopters of these varieties to control pervasive weeds more effectively. Commercially available HT crops include soybeans, corn, cotton, canola, sugarbeets, and alfalfa. Insect-resistant or Bt crops contain a gene from the soil bacterium *Bacillus thuringiensis* (Bt) that produces a protein which is toxic to certain insects, protecting the plant over its entire life (Fernandez-Cornejo and McBride, 2002). Commercially available Bt crops include corn and cotton.

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[1]Genetic engineering is a technique used to alter genetic material (genes) of living cells. A gene is a segment of DNA that expresses a particular trait. It is a unit of heredity transmitted from generation to generation during reproduction (Zaid et al., 1999). DNA constitutes the genetic material of most known organisms.

[2]Plant biotechnology in general and genetic engineering in particular have significantly reduced the time needed to develop improved plant varieties, increasing the range and precision of characteristics incorporated into these new varieties (Fernandez-Cornejo, 2004). By allowing scientists to target single plant traits through genetic recombination techniques, plant biotechnology decreases the number of residual unwanted characteristics that often result from traditional plant breeding crosses, enabling breeders to develop desirable new varieties more rapidly.

[3]Several second-generation GE crops have been approved by APHIS: high-lysine corn, reduced-nicotine tobacco, high-oleic acid soybean oil, stearidonic acid-producing soybeans, improved fatty acid-profile soybeans, altered-flower color roses (blue), oil profile-altered canola, and alpha amylase corn. Overall, nearly 20 percent of the approvals for deregulation (as of September 2013) are second-generation crops.

More than 15 years after commercial introduction, adoption of first-generation GE crop varieties by U.S. farmers has reached about 90 percent of the planted acres of corn, soybeans, and cotton. U.S. consumers eat many products derived from these crops—including cornmeal, oils, and sugars—largely unaware of their GE origins. Despite the rapid increase in adoption rates for GE corn, soybean, and cotton varieties by U.S. farmers, some continue to raise questions regarding the potential benefits and risks of GE crops.

This report updates ERS' 2006 report, *The First Decade of Genetically Engineered Crops in the United States.* As in the previous report, this report examines the three major stakeholders of agricultural biotechnology: GE seed suppliers and technology providers (biotech firms), farmers, and consumers.

From the Laboratory to the Field

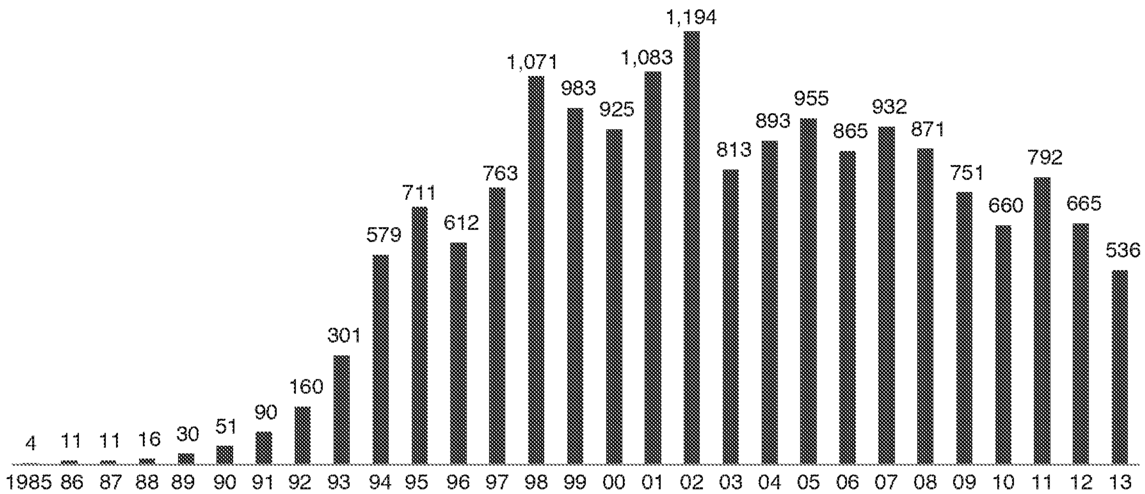
Over the last century, private research and development (R&D) expenditures in the seed industry have increased rapidly both in absolute terms and relative to public expenditures, altering the focus of R&D and of the crops studied (Fernandez-Cornejo, 2004). Over the past two decades, technological innovation in the form of modern biotechnology and changes in property rights have enabled private-sector firms to capture more value from the seeds that they develop, and seed remains the most research-intensive of the agricultural input sectors to date (Heisey and Fuglie, 2012).

While the rapid commercial success of GE varieties is the fulfillment of R&D efforts, earlier benchmarks include the number of releases for field testing of GE plant varieties approved by APHIS as well as the determination of nonregulated status (see box, "Regulatory Oversight").[4] Field testing is a critical part of seed development (Fernandez-Cornejo and Caswell, 2006).

Field Releases

The number of field release permits and notifications issued by APHIS for GE organisms (mostly plant varieties) grew from 4 in 1985 to 1,194 in 2002 and then averaged around 800 per year (fig. 1). The cumulative number (beginning in 1985 and ending in September 2013) of releases for field testing increased from 10,700 in 2005 to more than 17,000 in 2013. Field releases approved for corn increased from close to 5,000 in 2005 to 7,800 in 2013. Approved releases for GE varieties with herbicide tolerance traits increased from 3,587 in 2005 to 6,772 in 2013, insect resistance from 3,141 to 4,909, and product quality such as flavor or nutrition from 2,314 to 4,896.

Figure 1
Number of releases of genetically engineered (GE) organisms varieties approved by APHIS, 1985-2013* (Includes permits and notifications)



*As of September 24, 2013.
Authorizations for field releases of GE organisms (mostly plant varieties) are issued by USDA's Animal and Plant Health Inspection Service (APHIS) to allow technology providers to pursue field testing.
Source: Information Systems for Biotechnology (ISB, 2013).

[4] Another indicator of R&D activity is the number of patents issued by the U.S. Patent and Trademark Office. More than 4,200 new agricultural biotech patents were issued between 1996 and 2000 (King and Heisey, 2003, 2004).

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Regulatory Oversight

Before commercial introduction, genetically engineered (GE) crops must conform to standards set by State and Federal statutes (Fernandez-Cornejo and Caswell, 2006; USDA/APHIS, 2013). Under the Coordinated Framework for the Regulation of Biotechnology, Federal oversight is shared by the U.S. Department of Agriculture (USDA), the U.S. Environmental Protection Agency (EPA), and the U.S. Food and Drug Administration (FDA).

USDA's Animal and Plant Health Inspection Service (APHIS) plays a central role in regulating field testing of agricultural biotechnology products. Through either a notification or permit procedure, such products—which include certain genetically engineered plants, microorganisms, and invertebrates—are considered "regulated articles." APHIS issues authorizations for field releases of those GE organisms (mostly GE plants) that are categorized as "regulated articles" under its regulations, to allow technology providers to pursue field testing. GE plants that meet six specific criteria described in the regulations undergo an administratively streamlined process, known as a *notification*. Under a *notification*, applicants provide information on the nature of the plant and introduced genes, descriptions of genetic modifications, size of the introduction, and origin and destinations for movement or the location of a field test. For GE plants that do not meet the criteria for a *notification*, an APHIS *permit* is required. This process involves a more comprehensive review. In addition to the data required for notification, permit applicants must describe how they will perform the test, including specific measures to reduce the risk of harm to other plants, so the tested organisms remain confined and do not persist after completion of the field test.

After years of field tests, an applicant may petition APHIS for a determination of nonregulated status in order to facilitate commercialization of the product. If, after extensive review, APHIS determines that the GE organism is unlikely to pose a plant pest risk, the organism is issued a "determination of nonregulated status." At this point, the organism is no longer considered a regulated article and can be moved and planted without APHIS oversight under the biotechnology regulations (USDA/APHIS, 2012).

If a plant is engineered to produce a substance that "prevents, destroys, repels, or mitigates a pest," it is considered a pesticide and is subject to regulation by EPA (*Federal Register*, November 23, 1994). FDA regulates all food applications of crops, including those crops that are developed through the use of biotechnology, to ensure that foods derived from new plant varieties are safe to eat. A more complete description of the regulations of GE products may be found in USEPA, 2003; Belson, 2000; and USDA/APHIS, 2013).

Though the current regulatory system is considered to be effective, USDA, EPA, and FDA update regulations as needed to address new trends and issues of the future.

However, these numbers do not fully indicate the amount of R&D activity. A permit or notification can include many release sites and authorize many different gene constructs (ways that the gene of interest is packaged with other elements, like promoters that allow gene expression) to be tested at each site.[5] Thus, while the number of APHIS notifications and permits peaked in 2002, a more comprehensive measure of the amount of R&D activity in agricultural biotechnology—the number of authorized sites and authorized constructs—has increased very rapidly since 2005. For example, while the number of releases authorized in fiscal year (FY) 2012 was lower than in FY2005, the

[5]A gene construct is the technical name used for a functional unit necessary for the transfer or the expression of a gene of interest (http://www.gmo-safety.eu/glossary/667.gene-construct.html). Typically, a construct comprises the gene or genes of interest, a marker gene (to facilitate detection inside the plant), and appropriate control sequences as a single package (FAO, 2001).

number of authorized sites in FY2012 almost doubled those in FY2005 and the number of constructs increased more than 150-fold (table 1).[6]

Most field releases have involved major crops, particularly corn, which had about 7,800 field releases approved as of September 2013. More than 2,200 field releases were approved for GE soybeans, more than 1,100 for GE cotton, and about 900 for GE potatoes (fig. 2). Releases approved between 1985 and September 2013 included GE varieties with herbicide tolerance (6,772), insect resistance (4,809), product quality such as flavor or nutrition (4,896), agronomic properties (like drought resistance) (5190), and virus/fungal resistance (2,616) (fig. 3). A notable change in R&D activities

Table 1

Number of releases, sites, and constructs authorized by APHIS for evaluation

	Releases	Authorized sites	Authorized constructs
FY2012	767	9,133	469,202
FY2011	967	10,128	395,501
FY2010	754	6,626	297,422
FY2009	846	6,751	217,502
FY2008	948	7,744	125,365
FY2007	1,066	3,623	63,217
FY2006	974	4,327	18,532
FY2005	1011	4,939	3,042
FY2004	997	4,523	2,851
FY2003	824	2,910	2,650
FY2002	1,226	5,111	3,234
FY2001	1,190	5,831	3,208
FY2000	1,002	3,836	3,126
FY1999	1,068	4,134	3,502
FY1998	1,151	4,781	3,830
FY1997	782	3,427	2,650
FY1996	653	2,745	2,305
FY1995	734	3,690	2,666
FY1994	569	1,669	1,926
FY1993	341	455	870
FY1992	164	121	427
FY1991	90	10	226
FY1990	46	14	142
FY1989	32	12	74

A gene construct is the name used for a functional unit necessary for the transfer or the expression of a gene of interest (http://www.gmo-safety.eu/glossary/667.gene-construct.html). Typically, a construct comprises the gene or genes of interest, a marker gene (to facilitate detection inside the plant), and appropriate control sequences as a single package (Food and Agriculture Organization, 2001). A construct is a piece of DNA which functions as the vehicle or vector carrying the target gene into the recipient organism. It has several different regions.

Source: Unpublished USDA Animal and Plant Health Inspection Service database

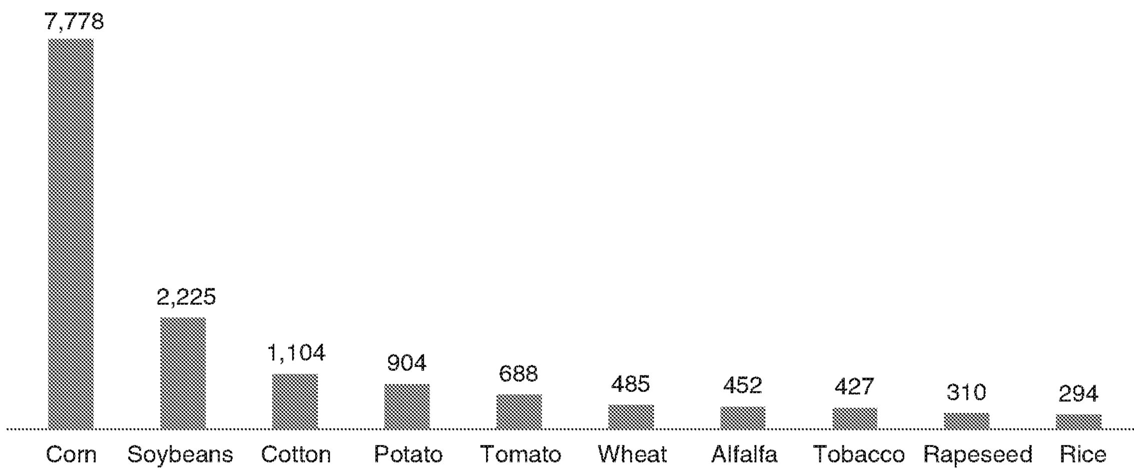
[6]Within each location there can be multiple sites or fields where the trial will be carried out (Information Systems for Biotechnology, 2013).

between 2005 and 2013, as measured by the field releases of GE varieties, is the five-fold jump in releases of GE varieties with agronomic properties (like drought resistance) from 1,043 in 2005 to 5,190 in 2013 (fig. 3).

The top release permit-holding institutions include Monsanto (6,782 permits/notifications held), Pioneer/DuPont (1,405), Syngenta (565), and USDA/ARS (370) (fig. 4).

Figure 2

Number of releases approved by APHIS: Top 10 crops (includes permits and notifications)*



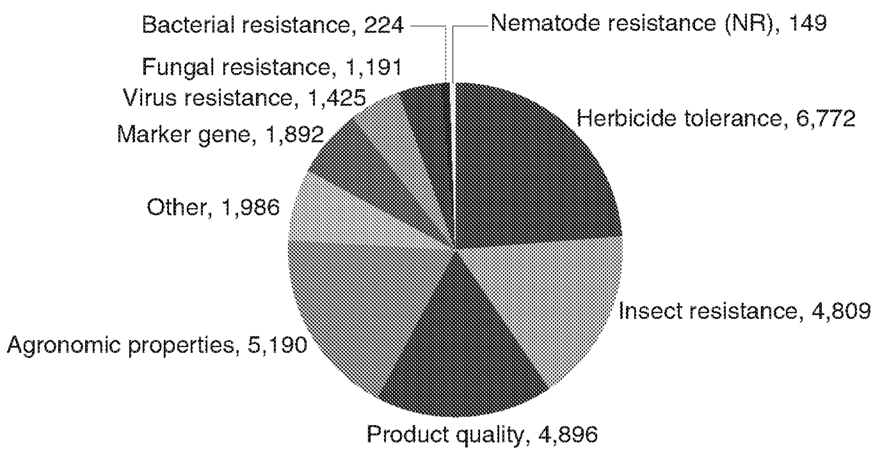
*As of September 24, 2013.

Authorizations for field releases of GE plant varieties are issued by USDA's Animal and Plant Health Inspection Service (APHIS) to allow technology providers to pursue field testing.

Source: Information Systems for Biotechnology (ISB, 2013).

Figure 3

Number of releases approved by APHIS by GE trait (includes permits and notifications)*

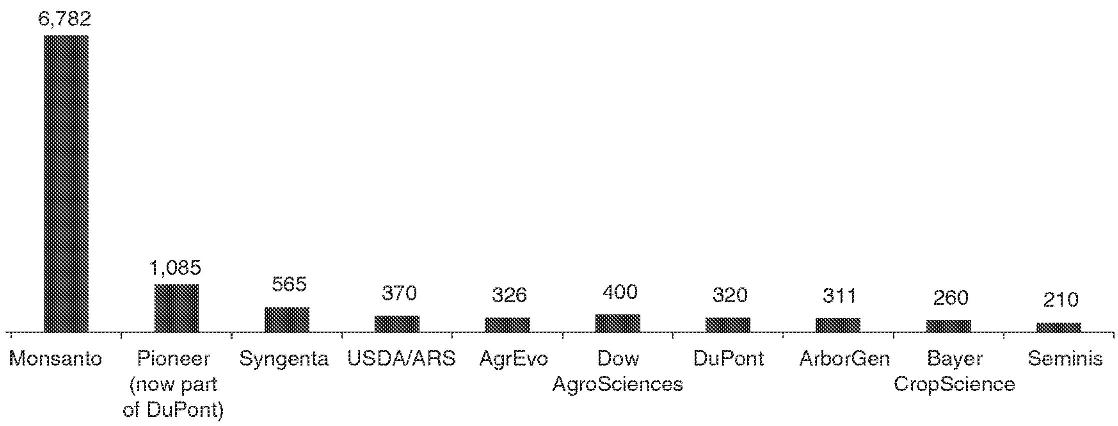


*As of September 24, 2013.

Authorizations for field releases of GE plant varieties are issued by USDA's Animal and Plant Health Inspection Service (APHIS) to allow technology providers to pursue field testing. Counts refers to the actual number of approved release locations per phenotype category. http://www.aphis.usda.gov/biotechnology/status.shtml

Source: Information Systems for Biotechnology (ISB, 2013).

Figure 4
Institutions having the most authorized permits and notifications (number held)



*As of September 24, 2013.

Authorizations for field releases of GE plant varieties are issued by USDA's Animal and Plant Health Inspection Service (APHIS) to allow technology providers to pursue field testing.

Source: Information Systems for Biotechnology (ISB, 2013).

Determination of Nonregulated Status

Nonregulated status allows seed companies to commercialize the GE seeds that they have developed. After successful field testing, technology providers petition APHIS for a determination of non-regulated status. If, after review, APHIS determines that the organism (i.e., GE plant) is unlikely to pose a plant pest risk, the organism is deregulated (see box, "Regulatory Oversight") and can be moved and planted without APHIS oversight. As of September 2013, APHIS had received 145 petitions for deregulation—compared with 103 petitions received in 2005—and had granted 96 (31 were withdrawn, 17 were pending, and 1 was incomplete) (Information Systems for Biotechnology, 2013). For corn, 30 petitions were granted nonregulated status; 15 were granted for cotton; 11 for tomatoes; 12 for soybeans; 8 for canola/rapeseed; 5 for potatoes; 3 for sugarbeet; 2 each for papaya, rice, and squash; and 1 each for alfalfa, plum, rose, tobacco, flax, and chicory. By trait, as of September 2013, 43 petitions were granted nonregulated status for herbicide tolerance, 31 for insect resistance, 17 for product quality, 9 for agronomic properties, 8 for virus resistance, and 2 for others.[7]

The Research and Development Pipeline

APHIS approval for field testing and determination of nonregulated status signals that the GE products are near commercial status. In addition to crops with improved pest management traits, APHIS approvals include crops with traits that provide viral/fungal resistance; favorable agronomic properties (resistance to cold, drought, frost, salinity, more efficient use of nitrogen, increased yield); enhanced product quality such as delayed ripening, flavor, and texture (fruits and vegetables); increased protein or carbohydrate content, fatty acid content or micronutrient content; modified starch, color (cotton, flowers), fiber properties (cotton) or gluten content (wheat); naturally decaffein-

[7]A petition (as well as an approval) may include more than one trait or phenotype category. For example, a petition for corn may include one or more HT traits and one or more Bt traits.

ated (coffee); nutraceuticals (added vitamins, iron, antioxidants such as beta-carotene); and pharmaceuticals (table 2).[8] Additional information is found in the Pew Initiative (2001), Runge and Ryan (2004), Monsanto (2012), and Pioneer (2012).

Table 2
Biotech crops currently available and in development

	Input traits				Output traits	
Crop	Herbicide tolerance	Insect resistance	Virus/fungi, resistance	Agronomic properties[11]	Product quality[14]	Pharmaceuticals/ nutraceuticals[17]
Corn	C	C[5]	D	C[12] D	D	D
Soybeans	C	D		D	C[15] D	
Cotton	C	C[6]		D	D	
Potatoes		W[7]	D	D	D	D
Wheat	C[2]		D			
Other field crops[1]	C[3] D[4]	D	D	D	D	D
Tomato, squash, melon, sweet corn		C[8]	C9 D	D	C[16] D	D
Other vegetables	D				D	
Papaya			C[10]			
Fruit trees			D		D	
Other trees				D[13]	D	
Flowers					D	

[1]Includes barley, canola, peanuts, tobacco, rice, sugar beet, alfalfa, etc.
[2]Monsanto discontinued breeding and field level research on its GE Roundup Ready wheat in 2004.
[3]Canola, sugar beet, alfalfa. [4]Barley, rice. [5]Bt corn to control the corn borer commercially available since 1996; Bt corn for corn rootworm control commercially available since 2003; Bt corn to control the corn earworm commercially available since 2010; stacked versions of them also available.
[6]Bt cotton to control the tobacco budworm, the bollworm, and the pink bollworm, commercially available since 1996.
[7]Bt potatoes, containing built-in resistance to the Colorado potato beetle were commercially introduced in 1996 and withdrawn in 1999.
[8]Sweet corn with insect resistance (to the corn earworm and European corn borer) was planted in anout 20,000 acres and sold in the fresh market in 2008 (NRC, 2010).
[9]VR squash accounted for about 12 percent of the squash produced in in 2005 (NRC, 2010).
[10]Responding to a devastating papaya virus epidemic in the mid-1990s, researchers at Cornell University and at the University of Hawaii developed two virus-resistant varieties of GE papaya. First commercial plantings were made in 1998. The new varieties were successful in resisting a viral epidemic and were planted on more than 30 percent of Hawaii's papaya acreage in 1999.
[11]Such as resistance to drought, frost, salinity; more efficient use of nitrogen.
[12]Drought tolerant corn approved for commercial use in 2011; expected to be introduced in 2012.
[13]Modified lignin content.
[14]Includes delayed ripening (fruits and vegetables with longer shelf life); protein content, carbohydrate content, fatty acid content, micronutrient content, oil content, modified starch content, flavor and texture (fruits and vegetables), color (cotton, flowers), fiber properties (cotton), gluten content (wheat), naturally decaffeinated (coffee), and low phytase.
[15]High oleic soybeans.
[16]FlavrSavr tomato genetically engineered to remain on the vine longer and ripen to full flavor after harvest was pulled out of the market because of harvesting and marketing problems.
[17]Includes increased vitamin, iron, beta-carotene (antioxidant), lycopene (anti-cancer), amino acid content; low-calorie sugar; hypoallergenic crops; antibodies, vaccines. Industrial uses (such as specialty machine oils).

Sources: ISB (2013); Fernandez-Cornejo and Caswell (2006); National Research Council (2010); USDA Animal and Plant Health Inspection Service.

[8]Pharmaceutical plant compounds produced are intended for pharmaceutical use and would need to be approved from at least one of the following agencies prior to commercialization: U.S. Food and Drug Administration (FDA) Center for Biologics Evaluation and Research (human biologics), FDA Center for Drug Evaluation and Research (human drugs), FDA Center for Veterinary Medicine (animal drugs), and USDA Center for Veterinary Biologics (animal biologics). None of the plants currently under permit produce pharmacologically active compounds.

Adoption of GE Crops by U.S. Farmers

When farmers adopt a new technology, they typically expect benefits like increased farm net returns, time savings (by making farming less effort intensive), or reduced exposure to chemicals. Net benefits are a function of farm characteristics and location, output and input prices, existing production systems, and farmer abilities and preferences.

Judging by the widespread adoption of GE seeds, farmers have benefited from them. U.S. farmers planted about 169 million acres of GE corn, soybeans, and cotton in 2013 (table 3), accounting for almost half of the estimated total land used to grow all U.S. crops.

On a global scale, approximately 420 million acres of GE crops were planted in 28 countries in 2012 (International Service for the Acquisition of Agri-biotech Applications, 2012). U.S. acreage accounted for approximately 41 percent of acres planted with GE seed. Brazil accounted for 21 percent, Argentina for 14 percent, Canada for 7 percent, India for 6 percent, and China, Paraguay, South Africa, and Pakistan each for roughly 2 percent.

Commercially introduced in the United States in 1996, major GE crops were rapidly adopted. Planting of GE crops (measured in acres) increased by 68 percent between 2000 and 2005 and grew by 45 percent between 2005 and 2013. Three crops (corn, cotton, and soybeans) make up the bulk of U.S. acres planted to GE crops (table 3), mostly for herbicide tolerance (HT) and insect resistance (Bt). Including varieties with HT and/or Bt traits, GE crops accounted for 90 percent of all planted cotton acres, 93 percent of soybean acres, and 90 percent of corn acres in 2013. U.S. farmers have

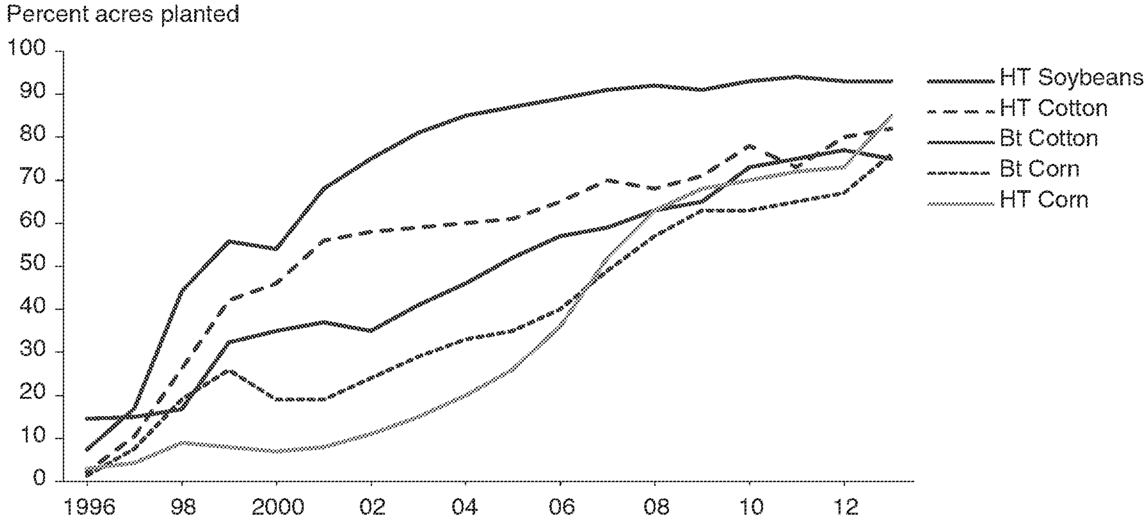
Table 3
Major genetically engineered crops, 2000-2013

Year	GE corn		GE soybeans		GE cotton	
	Million acres planted	Percent of corn acres	Million acres planted	Percent of soybean acre	Million acres planted	Percent of cotton acres
2000	19.89	25	40.10	54	9.47	61
2001	19.68	26	50.37	68	10.88	69
2002	26.82	34	55.47	75	9.91	71
2003	31.44	40	59.46	81	9.84	73
2004	38.04	47	63.93	85	10.38	76
2005	42.53	52	62.67	87	11.25	79
2006	47.78	61	67.21	89	12.68	83
2007	68.27	73	58.91	91	9.42	87
2008	68.79	80	69.66	92	8.15	86
2009	73.42	85	70.48	91	8.05	88
2010	75.85	86	71.99	93	10.21	93
2011	81.21	88	70.46	94	13.25	90
2012	85.50	88	71.79	93	11.58	94
2013	87.64	90	72.29	93	9.23	90

Genetically engineered crops in this table include Bt crops that have insect-resistant traits or HT crops that have herbicide tolerance traits, or both.

Sources: USDA Economic Research Service using data from from USDA/NASS Quick Stats and Fernandez-Cornejo (2013).

Figure 5
Adoption of genetically engineered crops in the United States



Bt crops have insect resistant traits; HT crops have herbicide tolerance traits.
Data for each crop category include varieties with both Bt and HT (stacked) traits.

Source: U.S. Department of Agriculture (USDA), Economic Research Service (ERS). 2013. *Adoption of Genetically Engineered Crops in the U.S.* data product.

tended to adopt HT seeds at higher levels than seeds with insect resistance (fig. 5). In part, this is because weeds are a pervasive problem.[9] HT adoption was particularly rapid in soybeans, with U.S. farmers increasing their planting of HT soybeans from 54 percent of soybean acres in 2000 to 87 percent in 2005 and 93 percent in 2013. HT cotton increased from 46 percent of cotton acres in 2000 to 61 percent in 2005 and 82 percent in 2013. HT corn increased from 7 percent of corn acres in 2000 to 26 percent in 2005 and 85 percent in 2013. Insect infestations tend to be more localized than weed infestations (fig. 6). Farmers planted Bt cotton (to control insects such as tobacco budworm, cotton bollworm, and pink bollworm) on 35 percent of the cotton acres in 2000, 52 percent in 2005, and 75 percent in 2013. Bt corn—commercially introduced to control the European corn borer in 1996, the corn rootworm in 2003, and the corn earworm in 2010—was planted on 19 percent of corn acres in 2000, 35 percent in 2005, and 76 percent in 2013.

Other GE crops commercially grown in the United States are HT canola, HT sugarbeets, HT alfalfa, virus-resistant papaya, and virus-resistant squash.[10] In addition, other traits are being developed and tested, including cold/drought resistance and enhanced protein, oil, or vitamin content (see table 2).[11]

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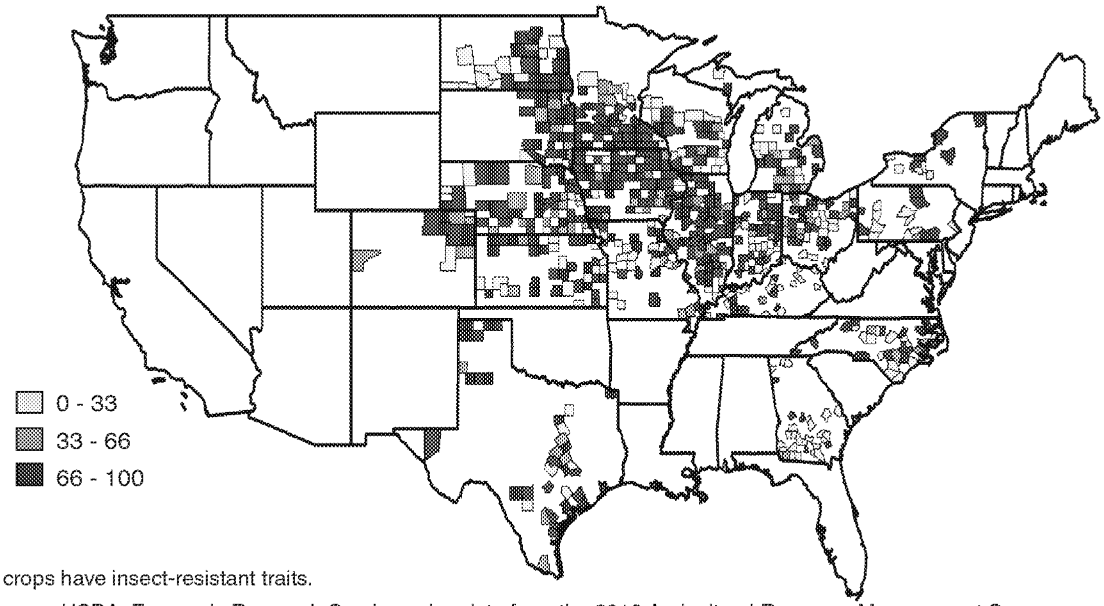
[9]Over 90 percent of U.S. acreage devoted to major crops has been treated with herbicides in recent decades (Osteen and Fernandez-Cornejo, 2012).

[10]Some other GE crops were only on the market for a limited amount of time. Bt potato varieties were introduced in 1996, but withdrawn from the market after the 2001 season. FlavrSavr tomatoes, which were genetically engineered to remain on the vine longer and ripen to full flavor after harvest, were introduced in 1994, but withdrawn from the market after several years.

[11]Drought-tolerant corn was approved for commercial use in 2011 (*Federal Register*, 2011; Monsanto, 2012) and commercially introduced in 2012.

Based on the Agricultural Resource Management Survey (see box, "ARMS Data"),[12] farmers indicate that they adopted GE corn, cotton, and soybeans primarily to increase yields (fig. 7). Other popular reasons for adopting GE crops were to save management time, to facilitate other production practices (such as crop rotation and conservation tillage), and to reduce pesticide costs.

Figure 6
Percentage of U.S. corn farmers who adopted Bt seeds in 2010



Bt crops have insect-resistant traits.

Source: USDA, Economic Research Service using data from the 2010 Agricultural Resource Management Survey (ARMS) Phase II corn survey.

The ARMS Data

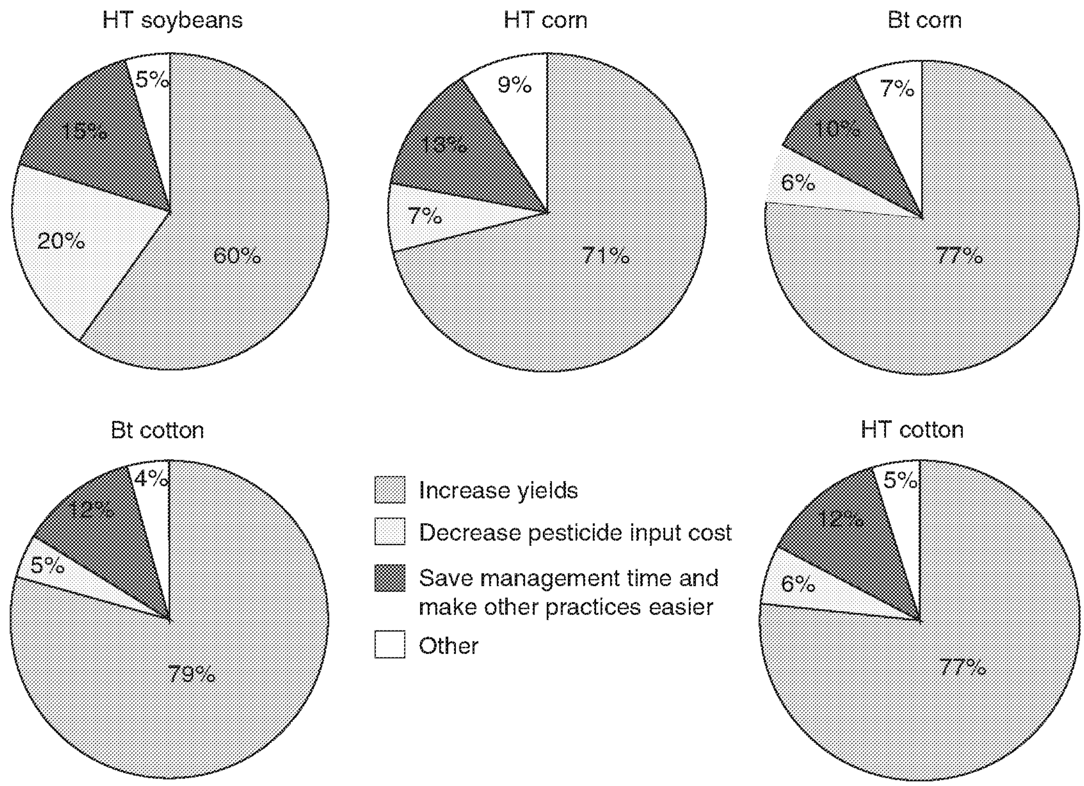
The Agricultural Resource Management Survey (ARMS), sponsored by USDA's National Agricultural Statistics Service (NASS) and the Economic Research Service (ERS), has a multi-phase, multi-frame, stratified, probability-weighted design. In other words, farmers with pre-selected characteristics are administered the ARMS each year. After data collection, NASS generates probability weights to help ensure that the ARMS sample accurately represents the population of U.S. famers.

The ARMS has three phases. Phase I, administered in the summer of the survey year, verifies that all respondents operate a farm or plant a specific crop. Phase II, administered in the fall or winter of the survey year, is a field-level survey that collects data on production practices and input use. Phase III, administered in the spring following the survey year, gathers data on debt, revenue, operating costs, and expenditures for the entire farm.

Phase I and Phase III are annual surveys that are administered to all respondents. Phase II is a commodity-specific survey that is administered annually for a rotating selection of crops. For instance, the ARMS Phase II Corn survey was administered in 2005 and 2010. The Phase II Soybean survey was administered in 2006 and the cotton survey was administered in 2007.

[12]USDA's National Agricultural Statistics Service (NASS) and Economic Research Service (ERS) sponsor the Agricultural Resource Management Survey (ARMS). This survey includes a crop-specific survey of production practices (called ARMS Phase 2) for selected major corps each once every 5 years on a rotating basis. This survey was conducted in 2006 for soybeans, 2007 for cotton, and 2010 for corn.

Figure 7
Farmers' reasons for adopting genetically engineered crops



Bt crops have insect resistant traits; HT crops have herbicide tolerance traits.

Sources: USDA Economic Research Service using data from Agricultural Resource Management Survey (ARMS) Phase II surveys: 2010 for corn, 2007 for cotton, and 2006 for soybeans.

Farm-Level Economic Impacts of GE Crop Adoption

The impacts of GE crop adoption vary by crop and technology. Many studies have assessed the factors that influence adoption as well as the impacts of GE crops on yields, net returns, and pesticide use (table 4; Fernandez-Cornejo and McBride, 2002).

Over the first 15 years of commercial use, GE seeds have not been shown to increase yield potentials of the varieties.[13] In fact, the yields of herbicide-tolerant or insect-resistant seeds may be occasionally lower than the yields of conventional varieties if the varieties used to carry the HT or Bt genes are not the highest yielding cultivars, as in the earlier years of adoption (Fernandez-Cornejo and Caswell, 2006; National Research Council, 2010).[14] However, by protecting the plant from certain pests, GE crops can prevent yield losses to pests, allowing the plant to approach its yield potential.

[13]Potential yield is defined as "the yield of an adapted cultivar when grown with the best management and without natural hazards such as hail, frost, or lodging, and without water, nutrient, or biotic stress limitations (water stress being eliminated by full irrigation or ample rainfall)" (Fischer and Edmeades, 2010). Farm level (actual or effective) yield is equal to potential yield minus the yield lost to pests or to other stresses.

[14]Since Bt and HT traits protect yield rather than increase potential yield, it is possible that in some cases the Bt and HT traits are not introduced in the highest yielding germplasm. Over time, this so-called "yield drag" usually disappears (NRC, 2010, Ch 3). On the other hand, Shi et al. (2013) show that the opposite situation may arise if GE genes are added more frequently to "high quality" germplasm. They call this situation genetic selectivity bias.

Table 4

Summary of selected studies on the effects of genetically engineered crops on yields, pesticide use, and net returns

Crop/researchers/date of publication	Data source	Effects on Yield	Effects on Pesticide use	Effects on Net returns
Herbicide-tolerant soybeans				
Delannay et al., 1995	Experiments	Same	na	na
Roberts et al., 1998	Experiments	Increase	Decrease	Increase
Arnold et al., 1998	Experiments	Increase	na	Increase
Marra et al., 1998	Survey	Increase	Decrease	Increase
Reddy and Whiting, 2000	Experiments	Same	na	Increase
Duffy, 2001	Survey	Small decrease	na	Same
Fernandez-Cornejo et al., 2002[1]	Survey	Small increase	Small increase	Same
McBride & El-Osta, 2002[2]	Survey	na	na	Same
Bradley et al., 2004	Experiments	Same	na	na
Marra et al., 2004	Survey	Same	na	Increase
Herbicide-tolerant cotton				
Vencill, 1996	Experiments	Same	na	na
Keeling et al., 1996	Experiments	Same	na	na
Goldman et al., 1998	Experiments	Same	na	na
Culpepper and York, 1998	Experiments	Same	Decrease	Same
Fernandez-Cornejo et al., 2000[1]	Survey	Increase	Same	Increase
Adhicari et al. 2000	Survey	na	na	Increase
Herbicide-tolerant corn				
Fernandez-Cornejo and Klotz-Ingram, 1998	Survey	Increase	Decrease	Same
Ferrell and Witt, 2002	Experiments	Same	na	Small increase
McBride & El-Osta, 2002[2]	Survey	na	na	Increase
Parker et al., 2006	Experiments	Same	na	na
Bt cotton				
Stark, 1997	Survey	Increase	Decrease	Increase
Gibson et al., 1997	Survey	Increase	na	Increase
ReJesus et al., 1997	Experiments	Same	na	Increase
Bryant et al., 19993	Experiments	Increase	na	Increase
Marra et al., 1998	Survey	Increase	Decrease	Increase
Fernandez-Cornejo et al., 2000[1]	Survey	Increase	Decrease	Increase
Falck-Zepeda et al., 2000[1]	Survey	Increase	na	Increase
Cattaneo et al., 2006	Survey	Increase	Decrease	na
Piggott and Marra, 2007	Experiments	Increase	na	Increase
Bt corn				
Rice and Pilcher, 1998[1]	Survey	Increase	Decrease	Depends on infestation

continued—

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Table 4
Summary of selected studies on the effects of genetically engineered crops on yields, pesticide use, and net returns—continued

Crop/researchers/date of publication	Data source	Effects on		
		Yield	Pesticide use	Net returns
Marra et al., 1998	Survey	Increase	Decrease	Increase
Duffy, 2001[2]	Survey	Increase	Na	Same
Baute, Sears, and Schaafsma, 2002	Experiments	Increase	Na	Depends on infestation
McBride & El-Osta, 2002[4]	Survey	Na	Na	Decrease
Pilcher et al., 2002[5]	Survey	Increase	Decrease	Na
Dillehay et al., 2004[6]	Experiments	Increase	Na	Na
Mitchell et al., 2004[7]	Experiments	Increase	Na	Depends on infestation
Fernandez-Cornejo and Li, 2005[8]	Survey	Increase	Decrease	Na
Mungai et al., 2005[9]	Experiments	Increase	Na	Na
Fang et al., 2007[10]	Experiments	Increase	Na	Na

na = not analyzed in the study; [1]Results using 1997 data; [2]Results using 1998 data; [3]Results are for 1996 and 1998, results were different for 1997 when the pest pressure was low; [4]Results using 1998 data; [5]Results using 1996-1998 data; [6]Results using 2004-2006 data; [7]Results using data from 1997-1999 ; [8]Results using data from 2001; [9]Results using data from 2002-2003, [10]Results using data from 2002.

The profitability of GE seeds for individual farmers depends largely on the value of the yield losses mitigated and the associated pesticide and seed costs.[15] GE adoption tends to increase net returns if the value of yield losses mitigated plus the pesticide savings exceeds the additional GE seed costs.

Adoption of Bt crops increases yields by mitigating yield losses to pests. Bt crops are particularly effective at mitigating yield losses. For example, before Bt corn was commercially introduced in 1996, the European corn borer was only partially controlled using chemical insecticides (Fernandez-Cornejo and Caswell, 2006). Chemical use was not always profitable, and timely application was difficult. Many farmers accepted expected yield losses of 0.4 to 3.2 bushels from this pest rather than incur the expense and uncertainty of chemical control (Hyde et al., 1999). After the introduction of Bt corn, adopters who had previously controlled corn borer infestations using insecticides lowered their pesticide costs and increased their yields. Adopters who had not previously treated European corn borer infestations with insecticides achieved only yield gains (and may have incurred higher seed costs).

In addition to improvements in background germplasm, Bt corn yields have increased over time as new insect resistance traits have been incorporated into the seeds and multiple (stacked) traits have become available (Fernandez-Cornejo and Wechsler, 2012). For instance, upon commercial introduction in 1996, Bt corn seeds were only resistant to one type of pest: the European corn borer. Since then, resistance to corn rootworms (2003) and corn earworms (2010) has been introduced.

[15]In this report, net returns are defined as per-acre revenues minus per-acre variable costs. Revenues per acre are equal to crop yields times crop price. Per-acre variable input costs include pesticide, seed and labor costs. Seed costs paid by adopters of GE varieties include a technology fee. This measure of net returns is used because most of the financial impacts of adopting GE crops result from changes in crop yields, chemical costs, and increased seed costs. This measure is estimated using field-level data and captures the greatest influence that GE crop adoption would have on farm financial performance as it also filters out the impact of other farm activities—such as livestock production (Fernandez-Cornejo and McBride, 2002). The econometric estimation involves estimating a restricted profit function (Fernandez-Cornejo and Wechsler, 2012) together with the associated supply function and input demand functions (hired labor is also included and wages are used as the *numeraire*).

Most experimental field tests and farm surveys show that Bt crops produce higher yields than conventional crops (table 4). Intuitively, Bt adopters are more likely to obtain higher yields than nonadopters by controlling insects and thus reducing yield losses to pests. The yield gain of Bt crops has become larger in recent years as new Bt traits have been incorporated into the seeds and multiple (stacked) traits have become available. For example, ARMS data show that the yield gain by Bt corn adopters relative to conventional varieties increased from 12.5 bushels per acre in 2001 to 16 bushels in 2005 and 26 bushels in 2010 (table 5; Fernandez-Cornejo and Li, 2005).[16] The geographical distributions of Bt adoption rates and average corn yields for 2010 are shown in figures 6 and 8, respectively.

While mean comparisons are illustrative, definitive conclusions about relative yields are possible only if the data are generated under experimental settings where factors other than adoption are controlled for by making them as similar as possible (Fernandez-Cornejo and McBride, 2002; NRC, 2010).[17] This is not the case with survey data.[18] Bt use is not random. Surveyed farmers are not randomly assigned to a treatment group (adopters) and a control group (nonadopters). Consequently, adopters and nonadopters may be systematically different from one another (for example, in terms of management ability). If these differences affect both farm performance and Bt adoption, they will confound the analysis (Fernandez-Cornejo and McBride, 2002; Fernandez-Cornejo et al., 2002). This self-selection[19] biases the statistical results unless it is corrected (Greene, 1997). Fernandez-

Table 5

Bt corn adopters and non-adopters, 2005 and 2010 (Samnple means of selected variables)

Variable	Unit	Bt	Non-Bt	Difference	Significance
2005					
Yield	Bushels/acre	155.1	138.6	16.6	***
Insecticide use	Pounds Ai/acre	0.05	0.09	-0.04	1
Corn price	Dollars/bushel	1.95	2.01	-0.06	NS
2010					
Yield	Bushels/acre	159.2	132.7	26.5	***
Insecticide use	Pounds Ai/acre	0.02	0.02	0.00	NS
Corn price	Dollars/bushel	5.39	5.40	-0.01	NS

*, **, and *** Indicates statistical significance at 10, 5, and 1 percent level, respectively.
NS = Not significant. [1]Significant at the 5-percent level when using standard procedures but not significant (p value 0.15) when using the delete-a-group jacknife procedure to estimate variances (Kott, 1998).
Source: USDA Economic Research Service using data from 2005 and 2010 Agricultural Resource Management Survey corn surveys.

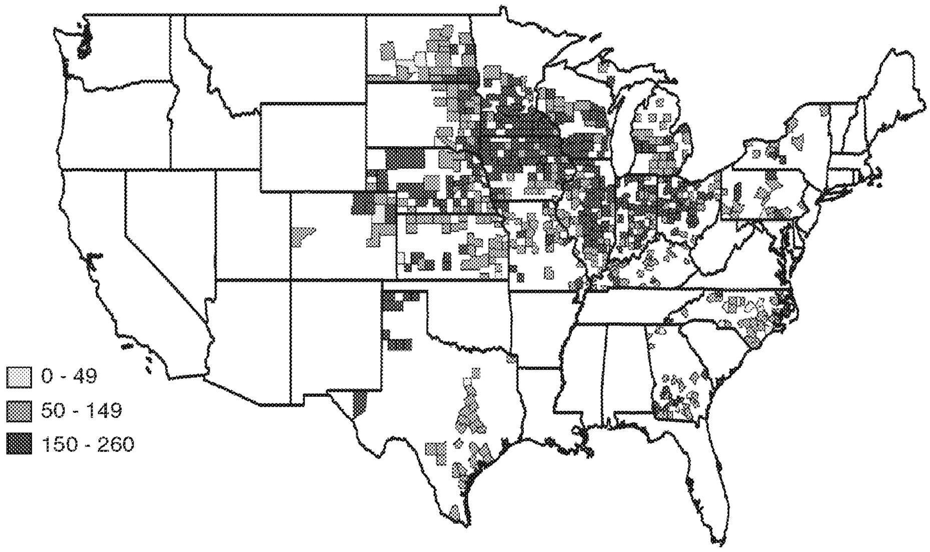
[16]The difference in means of corn yields between adopters and nonadopters is statistically significant for 2005 and 2010 using either the delete-a-group jackknife procedure (Kott, 1998) or the standard statistical test.

[17]The panel members who wrote the NRC report were Y. Carriere, W. Cox, D. Ervin, J. Fernandez-Cornejo, R. Jussaume Jr., M. Marra, M. Owen, P. Raven, L. Wolfenbarger and D. Zilberman.

[18]Marra et al. (2002a) provides an extensive discussion of the various types of biases that can arise when comparing means not only in farm (and field) surveys but in experimental settings as well (see box 3 for a discussion of the bias that may be caused by the halo effect).

[19]Self-selection is a type of endogeneity (Maddala, 1983; Greene, 1997). Endogeneity arises when there is a correlation between the explanatory variable and the model's residuals. If endogeneity is not accounted for (for instance, through the use of instrumental variable techniques), the results of the analysis will be biased. A common approach used to control for self-selection is sometimes called an instrumental variables approach. The model includes two stages. The first stage, which is referred to as the *adoption decision model*, is used to estimate the predicted values of the probability of adoption using a probit model. The second stage, or *impact model*, uses the predictions estimated in the first stage to estimate the impact of adopting Bt seeds on yields, seed demand, insecticide demand, and net returns.

Figure 8
Average yields (in bushels per acre) for U.S. corn farmers in 2010



Source: USDA, Economic Research Service using data from 2010 Agricultural Resource Management Survey (ARMS) Phase II corn survey.

Cornejo and Wechsler (2012) specified an econometric model to estimate the impact of adoption that accounts for self-selection. Using this model, they found that a 10-percent increase in the probability of adopting Bt corn was associated with a 1.7-percent increase in yields in 2005, and in a new ERS analysis using 2010 survey data, they found a 2.3-percent increase in yields (table 6). Using a similar econometric method to analyze cotton data, ERS researchers found that a 10-percent increase in the probability of adopting Bt cotton was associated with a 2.1-percent increase in yields in 1997 (Fernandez-Cornejo and McBride, 2002).

The effect of HT seeds on yields is mixed. The evidence on the impact of HT seeds on soybean, corn, and cotton yields is mixed (table 4). Several researchers found no significant difference between the yields of adopters and nonadopters of HT; some found that HT adopters had higher yields, while others found that adopters had lower yields. For instance, an ERS study found that a 10-percent increase in the adoption of HT cotton led to a 1.7-percent increase in cotton yields. HT soybean adoption was associated with a statistically significant, but small, increase in yields: a 10-percent increase in the probability of adopting HT soybeans was associated with a 0.3-percent increase in yields (Fernandez-Cornejo and McBride, 2002).

ARMS results show that HT soybean yields were 5 bushels per acre (3 percent) higher than conventional soybean yields in 2006 (but only significantly different at the 10-percent level) (table 7). In the case of corn, ARMS results show that HT corn yields were similar to those of conventional corn in 2010. However, unlike soybeans, the majority of corn (and cotton) producers in recent years use seed with stacked traits (figs. 9 and 10). Multiple stacked traits make evaluating the effect of individual GE traits on yields and profitability more complicated.

Stacked-trait seeds tend to have higher yields. An analysis of ARMS corn data indicates that stacked seeds (seeds with several GE traits) have higher yields than conventional seeds or seeds with only one GE trait. For example, 2010 ARMS data show that conventional corn seeds had an average

Table 6

The Impact of adopting Bt corn: Elasticities 2005, 2010[1]

	Elasticity with respect to the probability of adoption	
Variable	2005	2010
Net returns	0.17	0.23
Yield	0.17	0.23
Seed	0.1	0.21
Insecticide	NS	NS

[1]Elasticity measures the responsiveness of a variable (e.g., s, yield) to a change in another (e.g., adoption rate). It is unit free and always expressed in percentage terms.
Bt crops have insect-resistant traits
NS = Not significant.

Sources: 2005: Fernandez-Cornejo and Wechsler (2012). 2010: New analysis by Economic Research Service. (Model results using 2010 ARMS corn data. Model specification similar to that used by Fernandez-Cornejo and Wechsler, 2012).

Table 7

HT soybean adopters and non-adopters, 2006

Variable	Units	HT adopters	Non-adopters	Difference	Significance
Yield	Per acre yields, in bushels	45.6	40.6	5.0	*
Total herbicide use	Pounds AI per acre	1.36	1.05	0.31	NS
Glyphosate use	Pounds per acre	1.23	0.38	0.85	***
Other herbicides use	Pounds per acre	0.13	0.66	-0.53	**[1]

*, **, and *** Indicates statistical significance at 10-, 5-, and 1-percent level, respectively.
NS = Not significant.
[1]Significant at the 5-percent level when using standard procedures but not significant (p value = 0.14) when using the jacknife procedure to estimate variances (Kott, 1998).
HT crops have herbicide tolerance traits.

Source: Economic Research Service using data from 2006 Agricultural Resource Management Survey soybean survey.

yield of 134 bushels per acre in 2010. By contrast, seeds with two types of herbicide tolerance (glyphosate and glufosinate) and three types of insect resistance (corn borer, corn rootworm, and corn earworm) had an average yield of 171 bushels per acre. These results are consistent with findings by Nolan and Santos (2012), who analyzed a rich dataset of experimental hybrid trials collected by the extension services of 10 universities in major corn-producing States from 1997 to 2009.

Not surprisingly, adoption rates of stacked-seed varieties have increased quickly (figs. 9 and 10). Stacked corn seeds grew from 1 percent of the corn acres in 2000 to 9 percent in 2005 and 71 percent in 2013, while stacked cotton seeds grew from 20 percent to 34 percent in 2005, and 67 percent in 2013 (figs. 9-10). The most widely adopted GE corn varieties have both Bt and HT traits (table 8). Varieties with three or four traits are now common.

GE seed prices are influenced by stacking and many other factors. The market price of seed incorporates the costs associated with seed development, production, marketing, and distribution (Fernandez-Cornejo, 2004). The price must reflect farmers' willingness to pay while ensuring a profit margin after costs. Furthermore, the price depends on the competitiveness of the particular seed market, and the pricing behavior of those firms that hold large shares of the market (NRC, 2010).

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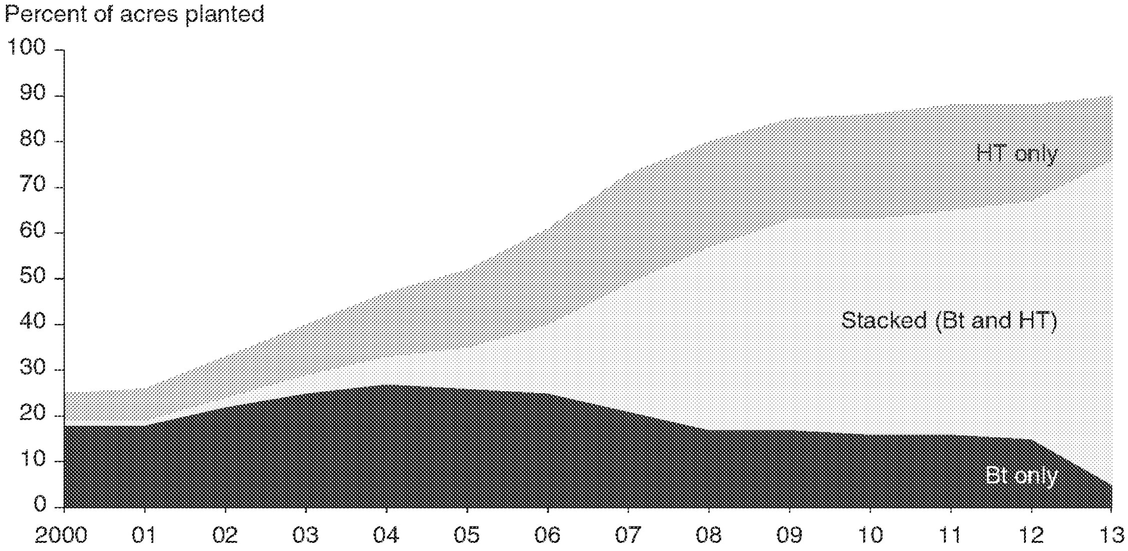
Figure 9

Adoption of genetically engineered corn: growth of stacked traits, 2000-2013

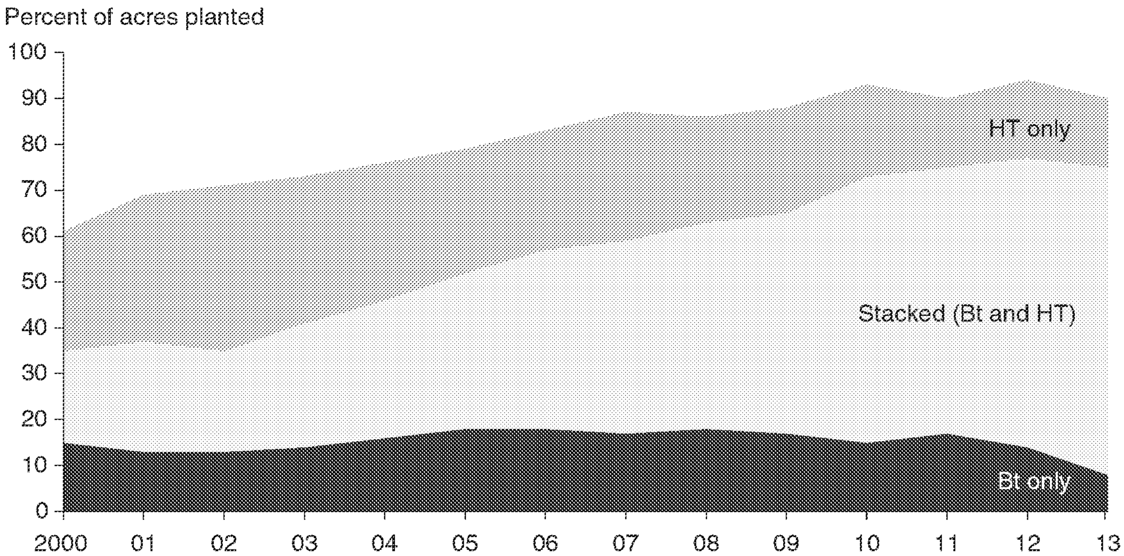


Bt crops have insect-resistant traits; HT crops have herbicide tolerance traits.

Source: U.S. Department of Agriculture (USDA), Economic Research Service (ERS). 2013. *Adoption of Genetically Engineered Crops in the United States,* data product.

Figure 10

Adoption of genetically engineered cotton: growth of stacked traits, 2000-2013



Bt crops have insect-resistant traits; HT crops have herbicide tolerance traits.

Source: U.S. Department of Agriculture (USDA), Economic Research Service (ERS). 2013. *Adoption of Genetically Engineered Crops in the United States,* data product.

In recent decades, private sector R&D costs have been rising with the application of new technologies, and much of the increase in seed prices has been associated with this trend (Krull et al., 1998). R&D costs vary among the different seed markets. For example, the corn seed market depends extensively on private sector R&D and passes these costs on to farmers. The wheat seed market

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Table 8

Adoption of genetically engineered varieties by U.S. corn producers, 2010

	GE traits (percent adopters)			
Seed Type	Bt only	HT only	Bt/HT	No GE
1. Genetically modified **herbicide resistant** seed variety (*e.g. LIBERTYLINK; ROUNDUP READY CORN*)		21.36		
2. Non-genetically modified **herbicide resistant** seed variety (*e.g. IMI-CORN*)				3.48
3. Genetically-modified **Bt** variety for insect resistance to control the European Corn Borer (**Bt-ECB**) (*e.g. YIELDGARD, YIELDGARD CORN BORER, HERCULEX I, NATUREGARD, KNOCKOUT*)	7.12			
4. Genetically modified **Bt** variety for insect resistance to control the corn rootworm (**Bt-CRW**) (*e.g. YIELDGARD ROOTWORM, HERCULEX RW*)	3.06			
5. **Stacked** gene (trait) variety with both genetically modified **Bt-ECB** and **Bt-CRW** (*e.g. YIELDGARD PLUS, HERCULEX XTRA*)	3.81			
6. **Stacked** gene variety with **two** genetically modified herbicide resistant traits (e.g. LIBERTYLINK + ROUNDUP READY)		3.73		
7. **Stacked** gene variety with both genetically modified **Bt-ECB** and **herbicide resistant** (*e.g. YIELDGARD + ROUNDUP READY, YIELDGARD CORN BORER WITH ROUNDUP READY CORN 2, HERCULEX I + LIBERTYLINK*)			9.77	
8. **Stacked** gene variety with both genetically modified **Bt-CRW** and **herbicide resistant** (*e.g. YIELDGARD ROOTWORM WITH ROUNDUP READY CORN 2, HERCULEX CW + ROUNDUP READY CORN*)			8.03	
9. **Triple stacked** gene variety with genetically modified **Bt-ECB** and **Bt-CRW** plus **herbicide resistant** traits (*e.g. YIELDGARD PLUS WITH ROUNDUP READY CORN 2, HERCULEX XTRA + LIBERTYLINK*)			25.91	
10. **Stacked** gene varieties that, in addition to the ECB and the rootworm, can control the corn earworm			5.71	
11. Multiple (more than three) **trait** stacked variety with several Bt traits and two herbicide resistant traits—glyphosate (Roundup) and glufosinate (Liberty)			1.24	
12. None of the above				6.79
Total	13.99	25.08	50.66	10.26

Source: USDA Economic Research Service using data from 2010 Agricultural Resource Management Survey corn survey.

depends largely on public sector research, which is largely cost free for farmers. There is no GE wheat commercially available.[20]

The real price index for seed rose nearly 30 percent faster than the average index of prices paid by U.S. farmers over 1996-2007 (NRC, 2010). The price of GE soybean and corn seeds grew by about

[20]Monsanto discontinued breeding and field level research on its GE Roundup Ready wheat in 2004.

50 percent in real terms (adjusted for inflation) between 2001 and 2010 (fig. 11). The price of GE cotton seed grew even faster (NRC, 2010).

The increase in GE seed prices can be attributed in part to increasing price premiums over conventional seeds (which include technical fees) associated with the rising share of GE seeds with more than one trait and/or more than one mode of action for particular target pests (NRC, 2010). Another factor contributing to the increase in GE seed prices is the improvement in seed genetics (germplasm) (NRC, 2010). The rapid adoption of GE crops indicates that many farmers are willing to pay higher seed prices because of improved seed performance and the additional pest management traits embedded in the GE seed.

Various studies of stacked GE seed varieties have found that stacked seeds are priced less than the sum of their component values (Stiegert et al., 2010). Shi et al. (2008, 2010) note that sub-additive pricing is consistent with "the presence of economies of scope in seed production." Moreover, these scope economies are consistent with "synergies in R&D investment (treated as a fixed cost)" across stacked seeds that can contribute to reducing total cost (Shi et al., 2010). Shi et al. (2009) found that while increased concentration in the seed industry has contributed to higher seed prices, complementarity effects in production and distribution mitigate these effects. Kalaitzandonakes et al. (2010-11) conclude that, while estimation of market power and associated price markups is not straightforward, the U.S. seed industry show both "moderate market power" and dynamic market efficiency (as indicated by the balance between firm profits and investments in product quality and innovation) over their period of analysis (1997-2008).

Adoption, Net Returns, and Farm Household Income

The impacts of GE crop adoption vary by crop and technology. Most studies show that adoption of Bt cotton and Bt corn is associated with increased net returns (table 4). However, some studies of Bt corn show that profitability is strongly dependent on pest infestation levels.[21] The impact of HT seeds (for corn, cotton, and soybeans) on net returns depends on many factors.

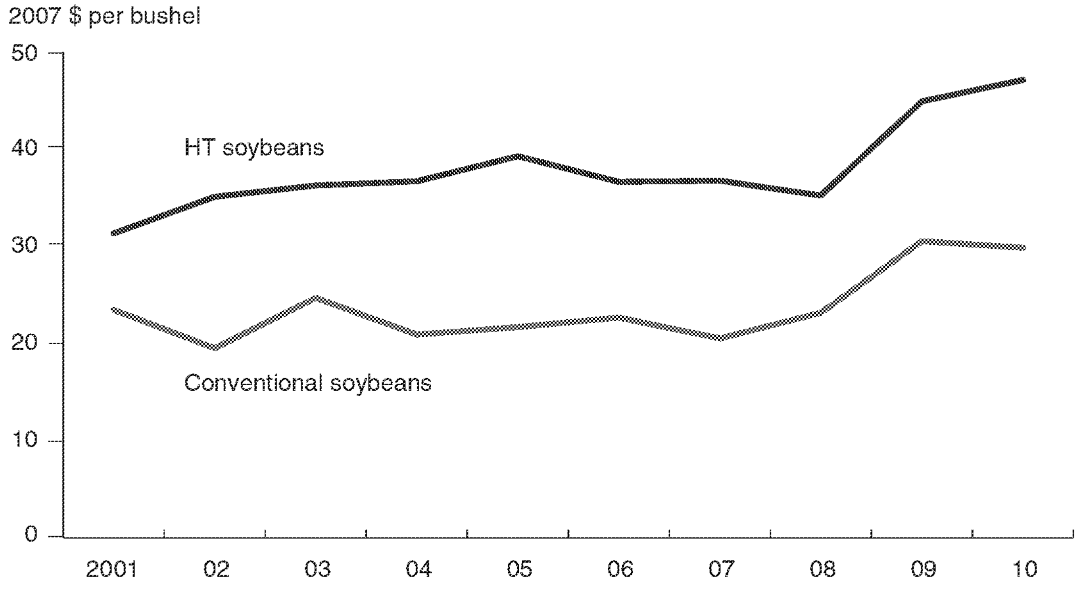
Planting Bt cotton and Bt corn is often more profitable than planting conventional seeds. ERS researchers found that adoption of Bt cotton was positively associated with net producer returns in 1997 (Fernandez-Cornejo and McBride, 2002). Using 2005 ARMS data, Fernandez-Cornejo and Wechsler (2012) found that a 10-percent increase in the probability of adopting Bt corn was associated with a 1.7-percent increase in net returns. In a new ERS analysis using 2010 ARMS data, we find that a 10-percent increase in the probability of adopting Bt corn was associated with 2.3-percent increase in net returns (table 6). Thus, there is essentially no change compared to earlier findings that planting Bt cotton and Bt corn is more profitable, as measured by net returns, than planting conventional seeds.

The effect of HT seeds on net returns depends on many factors. A primary advantage of herbicide-tolerant crops over traditional crops is cost savings (Fernandez-Cornejo and McBride, 2002). Producers who plant HT crops expect to achieve at least the same output while lowering weed

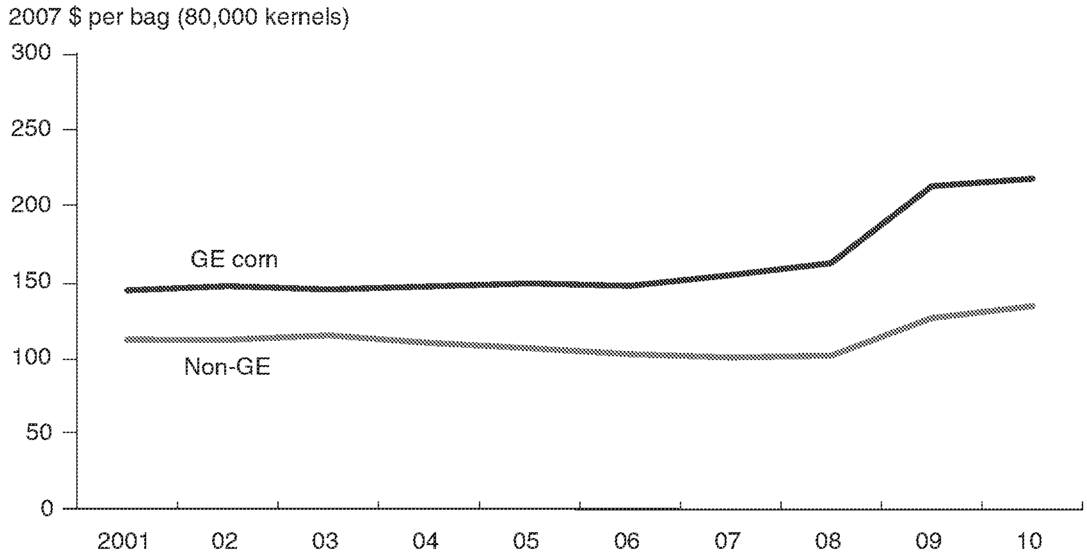
[21]Because pest pressure varies from one region to another, the economic benefits of Bt corn and consequently the rates of adoption vary regionally (fig. 6). Additionally, farmers must decide whether or not to use Bt corn before they know the severity of pest infestations, corn prices, or the price of insecticides. "Overadoption" may result from incorrect predictions (Fernandez-Cornejo and McBride, 2002). Alternately, farmers may be willing to adopt Bt seeds in order to reduce the risks associated with infestation levels that are higher than expected.

Figure 11

Prices of genetically engineered (GE) seed are higher than those of non-GE seed, soybeans



Prices of genetically engineered (GE) seed are higher than those of non-GE seed, corn



HT crops have herbicide tolerance traits.

Source: USDA Economic Research Service using data from USDA National Agricultural Statistics Service *Agricultural Prices*, various years.

control costs for chemicals and for mechanical methods, and minimizing the need for scouting. In return, producers pay more for HT seeds.

An additional economic effect is that the substitution of glyphosate, used in most herbicide-tolerant programs, for other herbicides decreases the demand for (and thus the price of) other herbicides

(Fernandez-Cornejo and McBride, 2002). Thus, the introduction of HT seeds may have lowered pesticide costs for both HT seed adopters and nonadopters.

Finally, HT seed-based production programs allow growers to use one product to control a wide range of both broadleaf and grass weeds instead of using several herbicides to achieve adequate weed control. Herbicide-tolerant crops also complement ongoing trends toward post-emergence weed control, the adoption of conservation tillage practices, and the use of narrow row spacing. The simplicity and flexibility of weed control programs for HT seeds require less management attention, freeing valuable management time for other activities (Fernandez-Cornejo and McBride, 2002).

HT seed has a mixed effect on net returns. The evidence on the impact of HT seeds (for corn, cotton, and soybeans) on net returns is mixed (table 4). Several researchers (Fernandez-Cornejo and McBride, 2002; Bernard et al., 2004; Marra et al., 2002) found that the adoption of herbicide-tolerant cotton has a positive impact on net returns. For example, Fernandez-Cornejo and McBride (2002) found that the elasticity of net returns with respect to the probability of adoption of herbicide-tolerant cotton was +0.18.[22] Bernard et al. (2004) found that adopting HT soybeans improved profits on Delaware farms. However, Fernandez-Cornejo et al. (2002) and McBride and El-Osta (2002) found no significant difference between the net returns of adopters and nonadopters of HT soybeans. Bullock and Nitsi (2001) found that HT soybean farmers are less profitable than their conventional counterparts. Overall, the empirical evidence on the impact of adopting herbicide-tolerant soybeans on net returns is inconclusive (NRC, 2010).[23]

The fact that several researchers found no significant differences between the net returns of adopters and nonadopters of HT crops (particularly HT soybeans) despite the rapid adoption of these crops suggests that many adopters may derive nonmonetary benefits from HT adoption. In particular, weed control for HT soybeans may be simpler, freeing up management time for leisure, enterprise growth, or off-farm income-generating activities.

HT crop adoption increases farm household income and has non-pecuniary benefits. ERS research shows that HT adoption is associated with higher off-farm household income for U.S. soybean farmers, most likely because time savings are used to generate income via off-farm employment (Fernandez-Cornejo et al., 2005). ERS researchers found that a 10-percent increase in the probability of adopting HT soybeans is associated with a 16-percent increase in off-farm household income. Household income from onfarm sources is not significantly associated with adoption of HT technology (Fernandez-Cornejo et al, 2007). These findings corroborate the notion that technology adoption is influenced by (or influences) the tradeoff between household/operator time spent in onfarm and off-farm activities. More recently, Gardner et al. (2009) confirm that genetically engineered crops lead to household labor savings in U.S. crop (corn and cotton) production. Using corn and soybean data, Marra and Piggott (2006) demonstrate that there are non-pecuniary benefits to GE crop adoption and show that farmers adopting GE crops place a monetary value on the convenience, flexibility, and increased worker safety associated with growing HT crops.

[22]Elasticity measures the responsiveness of a variable (e.g., net returns) to a change in another (e.g., adoption rate). It is unit free and is expressed in percentage terms.

[23]Given the high rates of adoption of HT soybeans (more than 90 percent in recent years), econometric studies using recent data are problematic because of the small size of the sample of nonadopters and the likelihood that there may be other factors influencing the decision not to adopt (e.g., organic farming) of that small group. This may lead to a stronger selection bias compared to studies using data from earlier years.

Adoption and Pesticide Use

Many studies based on field tests and farm surveys have examined the extent to which GE crop adoption affects pesticide (insecticide and herbicide) use, and most results show a reduction in pesticide use (table 4). A National Research Council study (2010) concurred that GE crops lead to reduced pesticide use and /or lower toxicity compared to conventional crops.

Insecticide use decreases with the adoption of Bt crops. Generally, Bt adoption is associated with lower insecticide use (table 4). Pounds of insecticide (per planted acre) applied to corn and cotton crops have declined over the course of the last 15 years (fig. 12). (Results for cotton in 1999-2001 were distorted because of the high application rates of the insecticide Malathion during the boll weevil eradication program.)

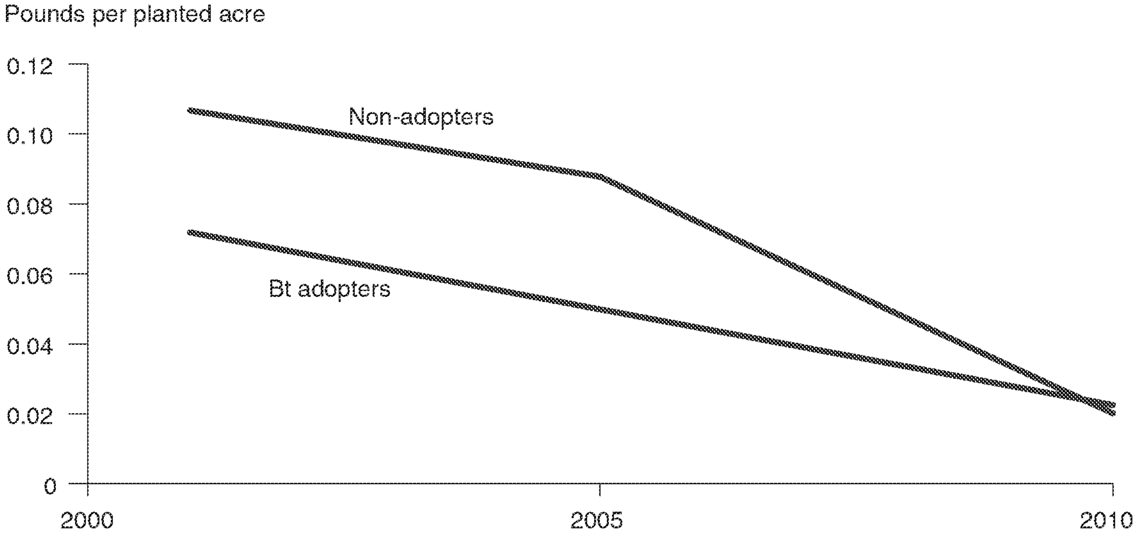
Insecticide use on corn farms declined most years and had an overall drop from 0.21 pound per corn planted acre of corn in 1995 (the year before Bt corn was commercially introduced) to 0.06 in 2005 and 0.02 pound in 2010 (fig. 12). Insecticide use has declined for both Bt adopters and nonadopters in recent years. According to ARMS data, only 9 percent of all U.S. corn farmers applied insecticides in 2010.

Econometric studies by ERS researchers have also found that, except for recent years, Bt crop adoption led to decreases in insecticide use, controlling for other factors. For example, Fernandez-Cornejo et al. (2003) show that the adoption of Bt cotton in the Southeast region (which had higher rates of Bt adoption) was associated with lower insecticide use on cotton in 1997. After controlling for other factors, a 10-percent increase in Bt corn adoption was associated with a decrease in insecticide use of 4.1 percent in 2001 (Fernandez-Cornejo and Li, 2005). However, Bt corn adoption was not significantly related to insecticide use in more recent years using 2005 data (Fernandez-Cornejo and Wechsler, 2012), as well as in a new ERS analysis using 2010 survey data (table 6).

Figure 12
Insecticide use in corn and cotton production, 1995-2010

Source: USDA Economic Research Service using data from USDA National Agricultural Statistics Service Agricultural Chemical Usage reports.

Figure 13
Insecticide use in corn farms: adopters and non-adopters of Bt corn, 2001-2010



Bt crops have insect-resistant traits.
Source: USDA Economic Research Service using data from 2001, 2005, and 2010 ARMS Phase II corn surveys.

Taken together, these results suggest that insect infestation levels on corn were lower in recent years than in earlier years and are consistent with findings by Hutchinson et al. (2010) that European corn borer populations have steadily declined over the last decade. Moreover, several researchers have shown that areawide suppression of certain insects such as the European corn borer and the pink bollworm are associated with the use of Bt corn and Bt cotton, respectively (see box, "Bt Crop Adoption and Areawide Pest Suppression").

Adoption of HT crops has mixed impact on herbicide use. Herbicide use on cotton and soybean acres (measured in pounds per planted acre) declined slightly in the first years following introduction of HT seeds in 1996, but increased modestly in later years (fig. 14a). Herbicide use on soybean farms has been mostly constant since 1996, but increased slightly starting in 2002 and peaked in 2006. Herbicide use on corn fell from about 2.6 pounds per acre in the early years of HT corn adoption to less than 2 pounds per acre in 2002 but increased moderately in recent years. Herbicide use on corn by HT adopters increased from around 1.5 pounds per planted acre in both 2001 and 2005 to more than 2.0 pounds per planted acre in 2010, whereas herbicide use by nonadopters did not change much (fig. 14b). HT adoption likely reduced herbicide use initially, but herbicide resistance among weed populations may have induced farmers to raise application rates in recent years, thus offsetting some of the economic and environmental advantages of HT corn adoption regarding herbicide use.[24]

The main effect of HT crop adoption on herbicide use is the substitution of glyphosate for more toxic herbicides. Despite the mixed but relatively minor effect HT crop adoption has had on overall herbicide usage, most researchers agree (NRC, 2010) that the main effect of HT crop adoption is the substitution of glyphosate for more traditional herbicides. Because glyphosate is significantly

[24]Adoption of conservation tillage by HT adopters may have also confounded these comparisons.

Bt Crop Adoption and Areawide Pest Suppression

Hutchinson et al. (2010) show that areawide suppression of the European corn borer is associated with Bt corn use. They estimate that the cumulative benefits of Bt adoption over 14 years exceed $6 billion for corn growers in Illinois, Minnesota, Wisconsin, Iowa, and Nebraska. Non-adopters captured $4.3 billion of these benefits because they reap the rewards associated with low infestation rates without paying a premium for insect-resistant seeds.

Carrière et al. (2003) conducted a 10-year study in 15 regions across Arizona and showed that Bt cotton suppressed a major pest, the pink bollworm, "independent of demographic effects of weather and variation among regions." Pink bollworm population density declined only in regions where Bt cotton was abundant. Such long-term suppression has not been observed with insecticide sprays, suggesting that deployment of Bt crops may also contribute to reducing the need for insecticide sprays.

Earlier, Marra et al. (2002a) considered the side-by-side trials of Bt and conventional varieties. They discuss the bias caused by the "halo effect" that arises from the insect suppression of the Bt crops spilling over onto the conventional treatments, thus increasing the yield of the conventional crop relative to what it would be if the conventional crop were grown in isolation. This effect biases downward the yield difference between the Bt and conventional varieties.

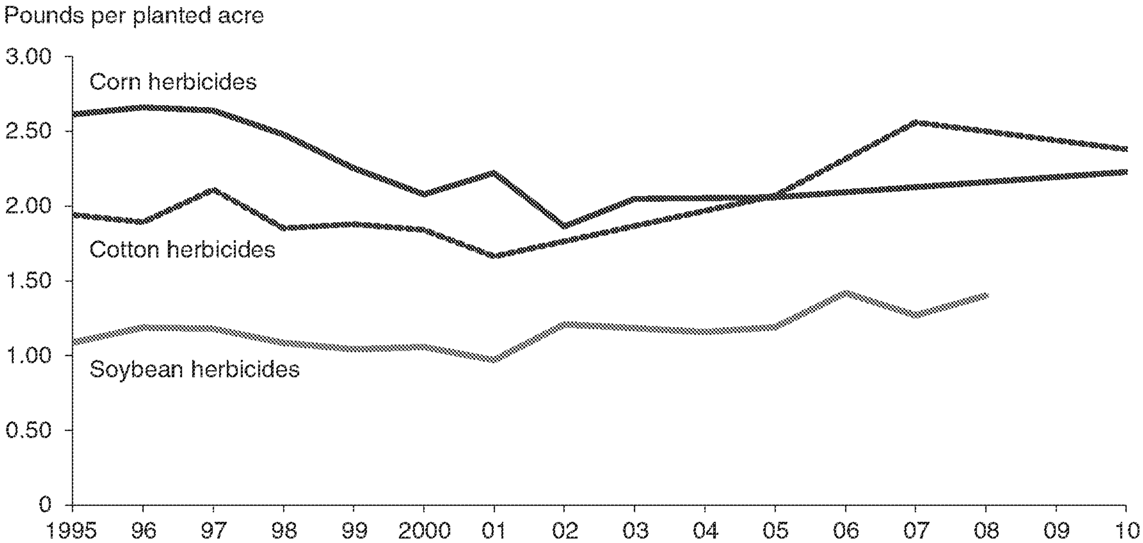
Based on data from 36 sites in 6 provinces of northern China over 1990-2010, Lu et al. (2012) found that there was an increase in beneficial insects (such as ladybirds and lacewings) and a decrease in pests (aphids) associated with the widespread use of Bt cotton reducing insecticide sprays.

less toxic and less persistent than traditional herbicides (WHO, 1994; NRC, 2010),[25] the net impact of HT crop adoption is an improvement in environmental quality and a reduction in the health risks associated with herbicide use (even if there are slight increases in the total pounds of herbicide applied).[26] However, glyphosate resistance among weed populations in recent years may have induced farmers to raise application rates. Thus, weed resistance may be offsetting some of the economic and environmental advantages of HT crop adoption regarding herbicide use. Moreover, herbicide toxicity may soon be negatively affected (compared to glyphosate) by the introduction (estimated for 2014) of crops tolerant to the herbicides dicamba and 2,4-D.

[25]However, recent publications have raised questions regarding the toxicity of glyphosate. Seralini et al. (2012) claim that GE corn and low levels of glyphosate herbicide formulations at concentrations well below officially-set safe limits induce severe adverse health effects, such as tumors, in rats. But a review of the study by the European Food Safety Authority (EFSA, 2012) concluded the Seralini et al. study as reported in the publication "is inadequately designed, analyzed and reported" and is "of insufficient scientific quality for safety assessments. As a result, the EFSA states that "conclusions cannot be drawn on the difference in tumour incidence between treatment groups on the basis of the design, the analysis and the results as reported." In a separate study, Mesnage et al. (2012) find that while toxicity of glyphosate has been safety tested on mammals, another ingredient used in commercial formulations used as adjuvant is toxic. More recently, Samsel and Sanoff (2013) claim that "glyphosate enhances the damaging effects of other foodborne chemical residues and environmental toxins."

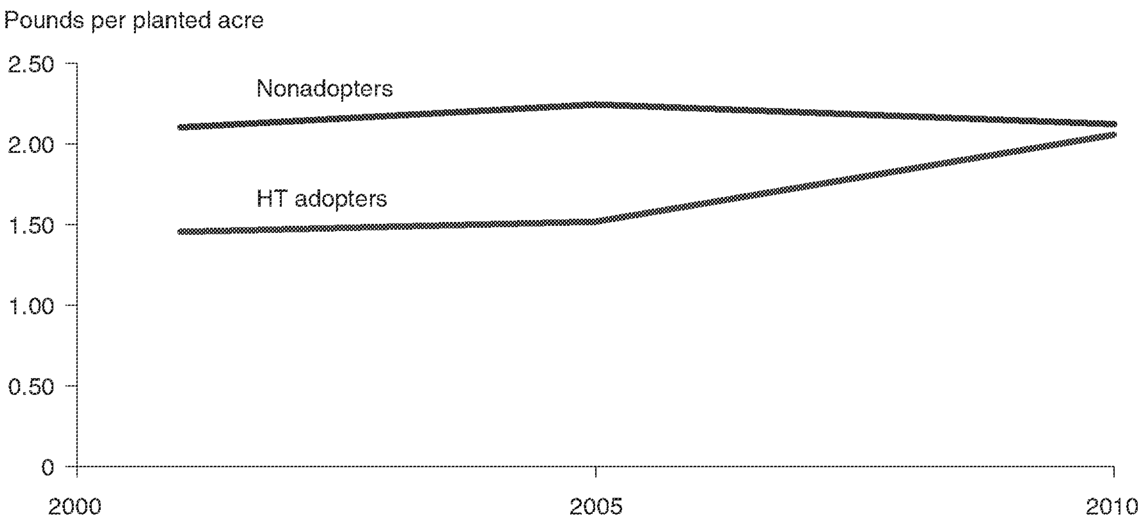
[26]HT crops also simplify the management of pesticide application (Carpenter and Gianessi, 1999). There is a greater window over which the herbicides can be applied (glyphosate can be effective on older plants). This makes it much easier to manage weather-related delays to the herbicide application schedule. Use of glyphosate also may reduce the need for aerial applications that are sometimes needed when it is too wet to enter the field.

Figure 14a
Herbicide use in cotton, corn, and soybeans, 1995-2010



Data for herbicide use for soybeans in 2007 and 2008 are from proprietary data.
Source: USDA/NASS Agricultural Chemical Usage reports and USDA/NASS Quickstats.

Figure 14b
Herbicide use on corn: HT adopters and nonadopters, 2001-2010



HT crops have herbicide tolerance traits.
Source: USDA Economic Research Service using data from 2001, 2005, and 2010 ARMS Phase II corn surveys.

Adoption and Conservation Tillage

Conservation tillage (including no-till, ridge-till, and mulch-till) is known to provide environmental benefits (USDA's ERS/NRCS, 1998; NRC, 2010). By leaving substantial amounts of crop residue (at least 30 percent) covering the soil surface after planting, conservation tillage reduces soil erosion by

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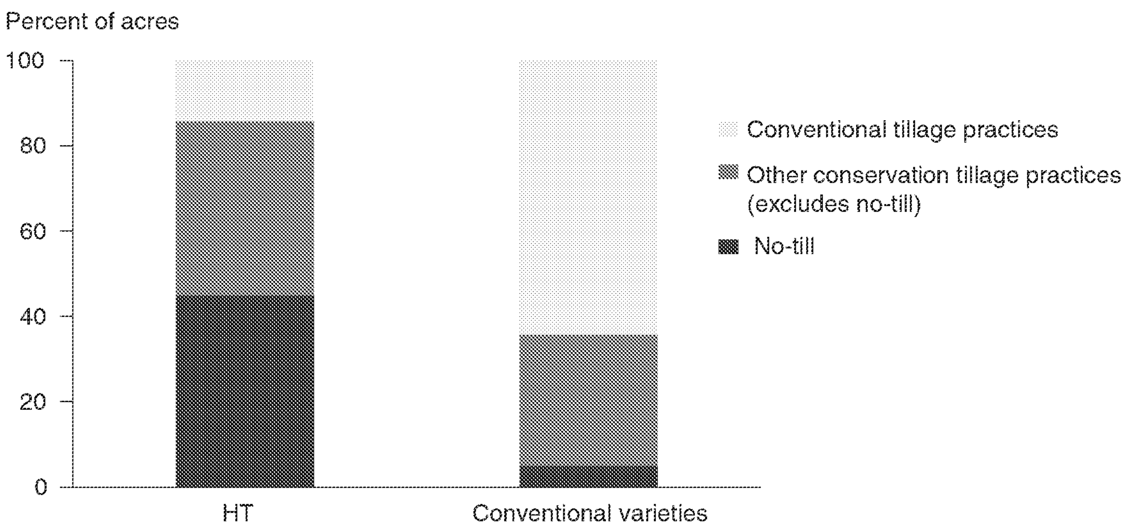
wind and water, increases water retention, and reduces soil degradation and water/chemical runoff. In addition, conservation tillage reduces the carbon footprint of agriculture.

Adopters of HT crops practice conservation tillage more than growers of conventional varieties. Since the 1980s, the adoption of conservation tillage practices by U.S. farmers has been facilitated by the availability of post-emergent herbicides that can be applied over a crop during the growing season. Post-emergent herbicides are especially beneficial in no-till production systems because these herbicides control weeds without tilling the soil. HT crops have helped spread no-till farming further since they often allow a more effective system than just using other post-emergent herbicides (Fernandez-Cornejo and Caswell, 2006).

According to USDA survey data, 60 percent of HT soybean planted acres used conservation tillage practices in 1997 versus 40 percent of conventional soybean acres (Fernandez-Cornejo and Caswell, 2006). By 2006, approximately 86 percent of HT soybean planted acres were under conservation tillage compared to only 36 percent of conventional soybean acres (fig. 15).

Differences in the use of no-till specifically are just as pronounced. While approximately 45 percent of HT soybean acres were cultivated using no-till technologies in 2006, only 5 percent of the acres planted with conventional seeds were cultivated using no-till techniques.[27] Cotton and corn data exhibit similar though less pronounced patterns. Thirty-two percent of HT cotton acres were planted using conservation tillage in 2007, compared to 17 percent of conventional cotton acres (fig. 16). Thirty-three percent of HT corn acres were planted using no-till in 2005, versus 19 percent of conventional corn acres (fig. 17).

Figure 15
Adopters of herbicide-tolerant crops used conservation tillage more than did growers of conventional varieties: soybeans, 2006



Conservation tillage includes no-till, ridge-till and mulch-till.
Source: USDA Economic Research Service using data from 2006 ARMS Phase II soybean survey.

[27]No-till systems are often considered the most effective of all conservation tillage systems. They leave 100 percent of crop residues on the soil surface and the soil is undisturbed from harvest to planting, resulting in the highest percentage of surface being covered by crop residues, minimizing soil loss and water runoff (Janssen and Hill, 1994).

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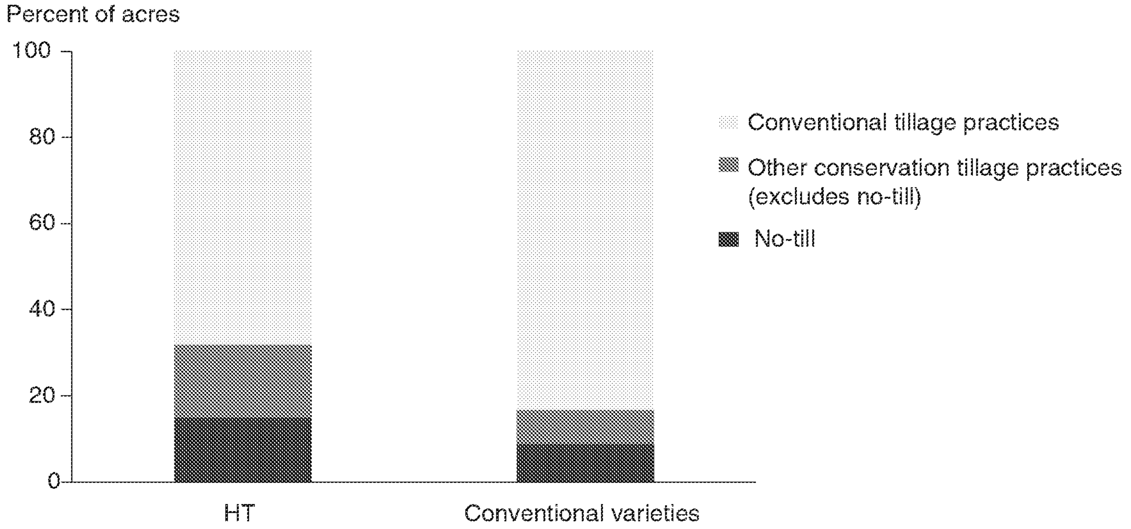
These trends suggest that HT crop adoption may encourage soil conservation practices. In addition, a review of several econometric studies point to a two-way causal relationship between the adoption of HT crops and conservation tillage (NRC, 2010). This implies that the adoption of herbicide-tolerant crops indirectly benefits the environment.

Figure 16

Adopters of herbicide-tolerant crops used conservation tillage more than did growers of conventional varieties: cotton, 2007

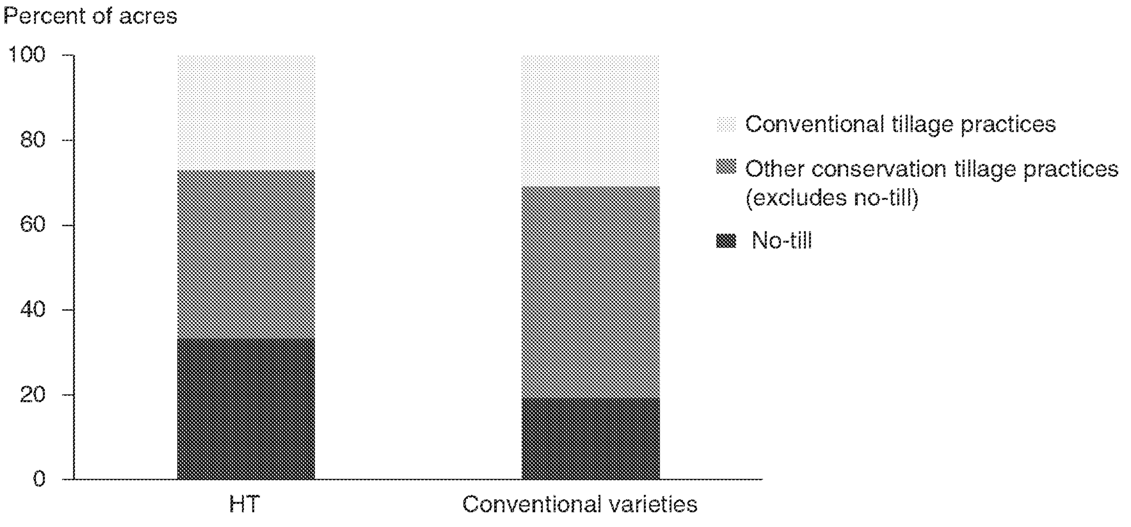


Conservation tillage includes no-till, ridge-till and mulch-till.

Source: USDA Economic Research Service using data from 2007 ARMS Phase II cotton survey.

Figure 17

Adopters of herbicide-tolerant crops used conservation tillage more than did growers of conventional varieties: corn, 2005



Conservation tillage includes no-till, ridge-till and mulch-till.

Source: USDA Economic Research Service using data from 2005 ARMS Phase II corn survey.

Pest Resistance Management and GE Crops

Pesticide resistance evolution occurs when pesticide use favors the survival of pests naturally resistant to the pesticide. Over time, these resistant pests become predominant in the pest population (see box, "Economics of Resistance Management"). Developers of Bt crops and other researchers recognized early on that insect resistance to Bt toxins could develop. Measures to delay the onset of such resistance (such as refuges) were taken and, so far, the emergence of insect resistance to Bt crops has been low and of "little economic and agronomic significance" (NRC, 2010), but there are some indications that insect resistance is developing to some Bt traits in some areas.[28] Also, since many users of HT crops rely solely on glyphosate to control weeds, resistance to this herbicide was anticipated by some researchers. Thus far, overreliance on glyphosate and a reduction in the diversity of weed management practices adopted by crop producers have contributed to the evolution of glyphosate resistance in 14 weed species and biotypes in the United States.

Insect Resistance to Bt Crops

Prior to the availability of Bt crops, entomologists and other scientists successfully argued that mandatory refuge requirements—planting sufficient acres of the non-Bt crop near the Bt crop—were needed to reduce the rate at which targeted insect pests evolved resistance. Such refuges slow the rate at which Bt resistance evolves by allowing target insects that are susceptible to the Bt toxin to survive and reproduce. To be effective, the refuge must be positioned appropriately and be large enough to ensure that insects that survive on the Bt acres mate with insects that survive on the non-Bt acres. Such interbreeding increases the chances that their progeny are susceptible, having inherited Bt resistance as a recessive trait.[29]

The U.S. Environmental Protection Agency (EPA) instituted mandatory refuge requirements as a condition of the registration of Bt corn and Bt cotton varieties for commercial use in the United States. This was the first time regulations were used to manage resistance to a pest control technology. Bt crop growers were required to sign a contract with their technology provider to comply with minimum refuge requirements, and technology providers were required to monitor and enforce grower compliance. An analysis of more than a decade of monitoring data suggests that the minimum refuge requirement, as well as natural refuges that also serve as hosts for target insect pests, has helped delay the evolution of Bt resistance (Tabashnik et al., 2008).

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[28]There is some indication of emergence of Bt-resistant corn rootworm in some parts of the Corn Belt http://www.bloomberg.com/news/2012-09-04/-mounting-evidence-of-bug-resistant-corn-seen-by-epa.html. http://bulletin.ipm.illinois.edu/article.php?id=1704. There is also anecdotal evidence that resistance is a contributing factor to increasing corn insecticide sales in 2012 and 2013 (I. Berry; *WSJ*, May 21, 2013). Tabashnik et al. (2013) recently analyzed 77 studies carried out in 5 continents from 1996 to 2012. They find that "although most pest populations remained susceptible, reduced efficacy of Bt crops caused by field-evolved resistance has been reported now for some populations of 5 of 13 major pest species examined, compared with resistant populations of only one pest species in 2005." They conclude that "the increase in documented cases of resistance likely reflects increases in the area planted to Bt crops, the cumulative duration of pest exposure to Bt crops, the number of pest populations exposed and improved monitoring efforts." They also conclude that while "regulations in the United States and elsewhere mandate refuges of non-Bt host plants for some Bt crops, farmer compliance is not uniformly high and the required refuge percentages may not always be large enough to achieve the desired delays in evolution of resistance. Both in theory and practice, using Bt crops in combination with other tactics as part of integrated pest management may be especially effective for delaying pest resistance."

[29]A dominant trait will be expressed in progeny if at least one of the parents has the gene for that trait. A recessive trait will be inherited if both parents have the gene for that trait. (Hedrick, 2000).

Economics of Resistance Management

When a pest population is confined to an individual farming operation, many of the benefits and costs associated with the farmer's pest control decisions accrue to and are borne by the farmer. In this hypothetical scenario, economic theory suggests that the pest population will be maintained at an economically efficient or socially optimal level.[1] However, when the pest moves from farm to farm, the pest control decisions made by any given farmer will affect the net returns accruing to that farmer, as well as those accruing to nearby farmers, although to a lesser extent. Because the effects of any farmer's control decisions on the regional pest population are practically negligible and because the benefits and costs associated with those effects are not borne by any given farmer (are not fully internalized), those effects might not be accounted for in the farmer's control decision. Because regional pest population dynamics are determined collectively by the decisions made by each farmer in the region, however, economic theory suggests that the pest population will not be maintained at a socially optimal level (Feder and Regev 1975).

This situation is referred to in the economics literature as a stock externality, an economic environment in which an individual ignores the impact of a decision that affects the level of a resource that is used by others (Gordon, 1954). In the presence of a stock externality, the resource might not be managed in a socially optimal manner. When the resource is a mobile pest population, Feder and Regev (1975) show how the introduction of a marginal user cost on pesticides, via a tax or a subsidy depending on the characteristics of the problem, can improve social welfare by ensuring that all of the net returns to pesticide use accrue to each user. The marginal user cost for a pesticide is the marginal expected present value of economic and environmental costs associated with the use of the pesticide, including impacts on regional pest population dynamics, impacts on the regional population dynamics of beneficial organisms that prey on the pest, and the evolution of resistance in the regional pest population to the pesticide, as well as the health effects associated with the accumulation of toxic pesticide residues and water/air pollution.

Pesticide resistance evolution is a process of artificial selection in which pesticide use favors the survival of particular insects and weeds and other pests resistant to the pesticide so that the frequency of resistant individuals in the population increases over time. In the presence of a mobile pest, farmers might not account for the effects of their pesticide use decisions on the evolution of resistance nor for the effects on regional pest population dynamics (Miranowski and Carlson, 1986). Hueth and Regev (1974) suggest that the institution of a tax equal to the marginal user cost could improve social welfare by ensuring that the costs associated with resistance are incorporated by farmers. Regev et al. (1983) examine such a tax in another theoretical analysis; however, noting the difficulty of applying the tax in practice, they suggest pesticide-use restrictions as an alternative.

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[1]For the purposes of this discussion, we are ignoring the costs associated with the accumulation of toxic pesticide residues, leaching of pesticides into surface and groundwater resources, and pesticide drift.

Refuge requirements depend on economic factors. Hurley et al. (2001) and Livingston et al. (2004) examine the characteristics of economically efficient refuge requirements for U.S. corn and cotton producers, respectively, for the single-toxin Bt corn and Bt cotton varieties. Both studies demonstrate that economic returns might be improved over the long run if corn and cotton producers comply with refuge requirements because of forestalling the onset of Bt resistance. The size of the economically efficient refuge requirement, however, was shown to depend on the length of the time horizon, the discount rate, and resistance evolution to conventional insecticides used to control target insect pests in the refuge acres. The refuge's ideal size was also shown to be extremely sensitive to how dominant the inherited Bt resistance trait is. Larger refuges are required to maintain susceptibility to Bt in target pest populations for longer time periods and when Bt resistance is inherited as a more dominant genetic trait by the target insect species.

Livingston et al. (2007) provide empirical support for the relaxation of mandatory refuge requirements for farmers who plant cotton varieties that express multiple Bt toxins in areas that have sufficient sources of unstructured refuge.[30] These varieties control the target pest species much more effectively than single-toxin varieties. Also, most U.S. cotton is grown in areas with sufficient sources of unstructured refuge—including both cultivated and uncultivated crops and plants that serve as alternative hosts for the target insect pest species, particularly the cotton bollworm and the tobacco budworm—effectively eliminating the need for a structured (or minimum) refuge requirement. Cotton growers in Arizona, California, New Mexico, and west Texas are still required to plant minimum, structured refuges.

Refuge requirements are reduced for multiple-toxin Bt cotton varieties in some areas. EPA has eliminated the minimum refuge requirement for certain Bt cotton varieties that express multiple toxins in areas that appear to have sufficient unstructured refuge, but not for Bt corn varieties that express multiple toxins. The latter are less toxic to an important target pest known as the western corn rootworm, which might inherit Bt resistance as a partially dominant trait. Recently, western corn rootworm larvae were collected from Iowa Bt cornfields that showed evidence of root damage, and laboratory assays later confirmed that their progeny were less susceptible to Bt toxins (Gassmann et al., 2011). This has raised concerns about regulatory compliance and a continued need for minimum refuge requirements for Bt corn growers.

Evolution of Glyphosate Resistance in Weeds

The herbicide glyphosate is more environmentally benign than the herbicides that it replaces. Glyphosate controls a wide array of weeds and is used on most of the HT corn, soybeans, and cotton grown in the United States. Glyphosate has been the most heavily used pesticide in the United States since 2001 (Grube et al., 2011), due in part to the popularity of HT crops and the steady decline in its price following the expiration of glyphosate's patent in 2000 (Duke and Powles, 2008).[31]

Because the pollen and seeds of many different weed species can disperse between farms in the atmosphere and in conjunction with the movement of animals and farm equipment, economic incentives for adopting best management practices (BMPs) that maintain the effectiveness of glyphosate

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[30]According to Andow et al. (2008), "a structured refuge is one that is planted near Bt cotton deliberately and an unstructured refuge relies on the other crops already grown as part of the local cropping system and where Bt is not used."

[31]Impending expiration of glyphosate patent protection in 2000 and the availability of generic glyphosate herbicides have led to a decrease in its price since 1998.

over time are reduced (Miranowski and Carlson, 1986).[32] The economic and biological impacts associated with any farmer's pesticide-use decisions will accrue not only to that farmer, but to other nearby farmers as well. Unless resistance management is coordinated across farms, economic incentives for farmers to account for the effects of their decisions on resistance are reduced, even on their own farms. This is because the effectiveness and longrun economic benefits of using BMPs to manage resistance depend on the level of adoption by nearby farmers, while the short-run costs of BMP adoption are borne solely by the adopters.[33] In this setting, resistance can evolve at an economically inefficient rate because market-based economic incentives are insufficient to promote an efficient level of BMP adoption (Hueth and Regev, 1974; Feder and Regev, 1975).

This reduction in economic incentives to adopt BMPs and the economic and environmental benefits associated with the HT crop-glyphosate combination have contributed to an overreliance on glyphosate and a concomitant reduction in the diversity of weed management practices by U.S. crop producers. This, in turn, has contributed to the evolution of glyphosate resistance in some weed species and a shift in weed composition in fields, favoring weeds that are naturally resistant to glyphosate. This leads to higher management costs, reduced yields and profits, and increased use of less environmentally benign herbicides. Glyphosate resistance is currently documented in 14 U.S. weed species (Heap, 2012), and the potential exists for much more acreage to be affected (Frisvold et al., 2009; Shaw et al., 2011).[34]

Because no new major herbicide chemistry has been made commercially available in the last 20 years, and because few new ones are expected to be available soon (Harker et al., 2012), many plant scientists believe that slowing the rate of glyphosate resistance and the spread of glyphosate-resistant (GR) weeds are among the most important problems facing U.S. crop producers (NRC, 2010, 2012). In addition, private and public programs seeking to promote the adoption of BMPs are in their infancy and do not address the reduced incentives to adopt BMPs caused by the ability of weed seeds to disperse between farms—the programs do not discourage the use of weed management practices that contribute to resistance.

Best management practices (BMP) may help sustain the efficacy of HT crops. Because weeds tend to inherit resistance to glyphosate as a dominant trait, the mandatory refuge requirement, which has been successful in sustaining the efficacy of Bt crops, might not be a viable option for HT crops (NRC, 2010). Depending on the weed, several BMPs, which are relatively difficult to monitor and enforce, might be required. These include using at least one other herbicide (particularly a residual herbicide that takes longer to decompose and thus stays in the soil longer), rotating crops, increasing the intensity of tillage, cleaning equipment between use in different fields to prevent the spread of weed seeds and pollen, and optimizing application by using the application rate recommended on the herbicide label and applying herbicides at the appropriate time and uniformly throughout the field. Some of these practices have been associated with increased weed management costs (Hurley et al., 2009), and many farmers, perhaps due partly to the incentive problems described above, are

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[32]Dauer et al. (2009) provide empirical evidence that horseweeds, one of the more important glyphosate-resistant weed species, can disperse between farms.

[33]BMPs include applying multiple herbicides with different modes of action at the recommended rates and developmental stages for the target weeds in the field, increasing the intensity of tillage to reduce the fraction of seeds that germinate, planting weed-free crop seed, scouting fields routinely, cleaning equipment to reduce the rate of introducing weeds to other fields, and preventing weed introductions by maintaining field borders (Norsworthy et al., 2012).

[34]Glyphosate resistance in weed species and biotypes in the United States is also due to glyphosate use in tree orchards, on roadsides, and on non-HT crops, where it is used before crops are planted and after they are harvested.

only adopting BMPs in the presence of glyphosate-resistant weeds, as opposed to adopting preventative approaches.[35]

Another approach currently being promoted by technology providers is the use of HT crops that are tolerant to two herbicides. However, the commercial availability of these types of crops does not address the incentive problem caused by the ability of weeds to disperse between farms. At least one HT crop provider is issuing rebates to growers who plant specific HT crop varieties, use glyphosate herbicides manufactured by that HT crop technology provider, and agree to use pre-emergent, residual herbicides.[36] The rebate program promotes the use of glyphosate in combination with other herbicides, which mitigates resistance; however, the program does not fully address the reduced incentive to adopt BMPs caused by the ability of weed seeds and pollen to disperse between farms.

USDA's NRCS recently initiated the Integrated Pest Management (IPM) Herbicide Resistance Weed Conservation Plan, which specifies guidelines for monitoring, recordkeeping, IPM, and conservation that satisfy criteria for soil, water, and air quality. Under the program, USDA pays farmers 75 percent of the cost of developing activity plans, which contain the minimum components needed to apply for cost-sharing assistance under the Environmental Quality Incentives Program (EQIP). This program can help promote the adoption of BMPs. However, in the absence of widespread adoption of BMPs, farmer participation might be insufficient to manage the evolution of glyphosate resistance in a manner that is optimal for crop producers.

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[35]Many farmers incorrectly assume there is no need to adopt BMPs because new herbicides will be available in the future (Norsworthy et al. 2012). In addition, the benefits of using BMPs occur in the future and are uncertain, as opposed to the certain increase in production costs.

[36]More information about this program is available at https://www.roundupreadyplus.com/Pages/Home.aspx.

Consumer Demand for GE Products

The successful marketing of crops produced via genetic engineering is contingent on consumer acceptance of these products (or products containing GE ingredients). Some consumers, including those in the European Union, have indicated a reluctance to consume GE products. In other countries, including the United States, expression of consumer concern is less widespread. Researchers studying markets in high-income nations often find that consumers are willing to pay a premium for non-GE products,[37] but recent studies have found that some consumers in developing countries, and others interested in second-generation traits like enhanced nutrition content, are more willing to consider GE foods. Information and types of GE technology may also affect consumer response to GE foods. In some countries, retailers have developed particular policies for GE ingredients in the foods they sell under their own brand names.

Willingness-to-Pay for GE and Non-GE Foods

Researchers have used a variety of methodologies to determine how much consumers are willing to pay for GE foods and how much they are willing to pay to avoid them (table 9). Some studies use the contingent valuation method, in which consumers are asked how much they would pay for non-GE foods. Other studies use experimental auctions, in which participants bid with actual money.

Consumers' responses on a survey, however, may differ from what they are actually willing to spend while shopping (Lusk, 2003). Meta-analyses of surveys indicate that when consumers are asked how much they value a good hypothetically, the values differ from what they actually will pay in a market setting, with the size of the difference dependent on such factors as whether consumers are asked how much they are willing to accept or willing to pay, the magnitude of the hypothetical price, the type of auction used or choices offered, and the type of good being evaluated (Murphy et al., 2005; List and Gallet, 2001). Murphy et al. (2005) found that models where respondents were asked to choose among alternatives, as opposed to developing their own, were associated with less hypothetical bias. On average, consumers tend to overstate what they would pay for goods, although in a significant minority of cases, they understated what they would pay. The willingness-to-pay values therefore may only approximate what consumers will actually pay.

Mather et al. (2011), combining surveys with market methodology, found that when consumers in five EU countries plus New Zealand were surveyed, they selected organic over conventional or GE fruit.[38] However, when actual fruit stalls were set up offering three different varieties of fruit, consumers in Sweden, New Zealand, and Germany bought more of the GE varieties, also labeled "spray-free," but only when they were offered at a 15-percent discount.

Consumer Acceptance of GE Foods in High- and Low-Income Countries

Research on consumer acceptance of GE foods in high-income countries such as the United States, UK, and Canada finds that consumers are willing to pay a premium for non-GE foods

[37]Non-GE foods can be more expensive if they cost more to produce, or if marketing streams must be kept separate.

[38]Consumers who asked about the GE fruit were told that it contained genes that caused it to produce a natural insecticide. GE fruit is not commercially available in these countries, and consumers who expressed surprise about this were told the fruit may have come from an experimental orchard (Mather et al., 2011).

Table 9

Studies in which consumers were willing to pay a premium for non-GE food

Country	Good	Study	Willingness to pay premium [1]
United States	Potatoes and corn	Bernard and Bernard, 2010	In experimental nth price auction, found positive premium for non-GE food
United States	Various	Huffman, 2010	In experimental nth price auction, found 15-percent discount for GE food, but difference was only statistically significant for one of three foods
United States	Tomatoes	Bukenya and Wright,2007	Surveyed Alabama consumers willing to pay a $0.39 or 19-21 percent premium for non-GE tomatoes
United States	Vegetable oil, tortilla chips, and potatoes	Huffman et al., 2007	Found consumers willing to pay 14 percent less for GE foods
United States	Vegetable oil	Tegene et al., 2003	In experimental auctions, consumers willing to pay 14 percent more for non-GE food
United States	Potatoes	Loureiro and Hine, 2002	Customers willing to pay 5 percent more for non-GE food
United Kingdom	All foods	Burton et al.,2001	Customers indicated willingness to increase food budgets by 26-129 percent to avoid GE foods
United States, France, Germany, United Kingdom	Beef fed with GE feed	Lusk et al., 2003	U.S. consumers willing to pay $2.83 and $3.31 per lb. to avoid biotech; European consumers $4.86 to $11.01
United States, United Kingdom	Breakfast cereal	Moon and Balasubramanian, 2001	Found 56 percent of UK consumers willing to pay a premium to avoid GE food, compared to 37 percent of U.S. consumers.
United Kingdom	Various	Moon et al., 2007	Found that consumers were willing to pay a 20-percent premium for non-GE products and willing to accept a discount of 23 percent for GE foods
UK, Belgium, France, Germany, New Zealand, Sweden	Fruit	Mather et al., 2011	Found that surveyed consumers offered organic, conventional, or GM fruit stated that they wanted organic, but the same consumers at roadside stalls bought GM (labeled spray-free and offered at a 15-percent discount) 15-43 percent of the time
Germany	Canola	Hartl and Herrmann, 2009	In an online survey, found that the GE version must be discounted by over 100 percent
Romania	Potatoes, Sunflower oil	Curtis and Moeltner, 2007	Found that so few of surveyed Romanians were willing to purchase GE foods that a premium could not be calculated
Sweden	Beef, chicken	Carlsson et al., 2007	Found that consumers were willing to pay 30 SEK/kg extra for chicken and 32.5 SEK/kg for beef fed feed not produced using GE ingredients

continued—

Table 9

Studies in which consumers were willing to pay a premium for non-GE food—continued

Country	Good	Study	Willingness to pay premium [1]
Norway, United States, Japan, Taiwan	Vegetable oil	Chern et al., 2002	For non-GE vegetable oil, Norwegian students were willing to pay $1.51 (55-69 percent premium) per liter. U.S. students were willing to pay $1.13 (50-62 percent premium), Japanese students were willing to pay $0.88 (33-40 percent premium), and Taiwanese students were willing to pay $0.45 (17-21 percent premium)
Norway	Bread	Grimsrud, et al., 2004	Consumers required discounts of 37 to 63 percent to buy GE bread; one-fourth were willing to buy with no discount
Australia	Beer	Burton and Pearse, 2002	Younger Australian consumers would pay $A 0.72 less and older consumers $A 0.40 less for beer made with GE barley
Canada	Canola	Volinskiy et al, 2009	In a shopping experiment, found that consumers would pay Canadian $0.45 (20-30 percent) premium for non-GE canola
Canada		West et al., 2002	83 percent of consumers ascribed a lower value to several GE food products
China	Vegetable oil	Hu et al., 2006	Consumers would consume GE product with a 14-percent discount after hearing basic or positive information, and a 66-percent discount after hearing negative information
China	Soybean oil and rice	Lin et al., 2006	Consumers on average would pay a 52-percent premium for non-biotech foods
France	Biscuits	Noussair, et al., 2004	35 percent of consumers were unwilling to purchase GE foods, and 42 percent were willing to purchase them if they were less expensive
United States	Various	Rousu et al., 2004	Consumers reduced their demand by an average of 7-13 percent for each food product having 1-percent and 5-percent tolerance levels for GE material relative to food not produced using GE ingredients

[1] Lusk et al., 2005 contains a more exhaustive review of the literature prior to 2005.

(Bernard and Bernard, 2010; Huffman, 2010; Hartl and Herrmann, 2009; Volinskiy et al., 2009; Bukenya and Wright, 2007; Moon et al. 2007; Huffman et al., 2007; Carlsson et al., 2007; Tegene et al., 2003; Loureiro and Hine, 2002; Burton et al., 2001; Lusk et al., 2003; Moon and Balasubramanian, 2001). Other research studies have identified concerns about GE foods (Bernard et al., 2007; Komirenko et al., 2010).

Lusk et al. (2005) found that much of the variation in premia for non-GE foods across studies can be explained by a number of factors, including whether the study was done in Europe, whether the research surveyed shoppers, whether the survey took place in person, whether the consumers were asked to give hypothetical values for willingness-to-pay, whether they were asked for values for GE or non-GE foods, what type of product was considered, and whether consumers were told the product would provide them with a direct benefit.

More recent research on consumer willingness-to-pay for GE foods has focused on consumers in developing countries and has yielded different results than in wealthier nations (table 10). Several authors found that consumers are willing to pay a slight premium for GE foods in India (Krishna and Qaim, 2008; Anand et al., 2007), Kenya (Kimenju and De Groote, 2008), and China (Li et al., 2002). The few studies that have considered second generation attributes like nutrition have also found willingness-to-pay a premium for GE foods in India and Brazil (Anand et al., 2007; Gonzalez et al., 2009a). However, these findings are not universal across all developing countries. Hu et al. (2006) found that, on average, consumers in Nanjing would consume GE vegetable oil at a discount of 14 percent if presented with basic information or positive information and would require a discount of 66 percent if presented with negative information. Lin et al. (2006) also found that Chinese consumers would pay an average premium of 52 percent for non-GE foods. In addition, in Romania, a lower income country that is also in the EU, Curtis and Moeltner (2007) could not calculate a premium for non-GE goods over GE goods since too few in their survey of Romanians were willing to purchase GE goods. A cluster analysis of Brazilian stakeholders in the debate over

Table 10

Studies in which consumers were willing to pay a premium for genetically engineered (GE) food or GE food with enhanced characteristics

Country	Good	Study	Willingness to pay premium [1]
United States	Good	Huffman, 2010	Found that consumers would pay a 19- to 26-percent [2] premium for a product with intragenic addition of vitamins over a plain labeled product
United States	Golden Rice	Lusk, 2003	Customers willing to pay $0.93 for GE “golden rice” with added vitamin A, $0.65-0.75 for regular rice
Germany	Canola	Hartl and Herrmann, 2009	In an online survey, also found that consumers were willing to pay 1.37 Euros/half-liter extra for GE oil with Omega3’s and 0.80 euros per half-liter for GE oil with cholesterol-reducing compounds, which reduced but didn’t eliminate the GE discount
Italy		Bocatelli and Moro, 2001	Consumers willing to pay a positive amount for GE attributes; 66 percent did not require a premium to consume GE foods
China	Rice	Li et al., 2002	80 percent of consumers did not require a premium to purchase GE rice and on average were willing to pay a 38-percent premium for GE rice and a 16-percent premium for GE soy oil
Brazil	Vitamin A fortified cassava	Gonzalez et al., 2009	Found surveyed consumers willing to pay 64-70 percent more for GE Vitamin-A fortified cassava
India	Bt vegetables	Krishna and Qaim, 2008	Found surveyed consumers willing to pay 1.5 percent premium for GE Bt (pest resistant) vegetables
India	Wheat	Anand et al., 2007	Found that if given no info, consumers will pay a 7-percent premium for GE foods; positive info leads to a 10-percent premium, negative info leads to a negative 139-percent premium (discount) for GE foods, and positive info on heart-healthy characteristics leads to a 23-percent premium for GE foods
Kenya	Maize meal	Kimenju and De Groote, 2008	Consumers surveyed in 2003 would pay a 13.8-percent premium for GE food

[1] Lusk et al., 2005 contains a more exhaustive review of the literature prior to 2005.

[2] Across all information treatments.

GE foods found that while many respondents perceived little or no risk from GE foods, some were skeptical of the benefits (Gonzalez et al., 2009b).

Some studies found that consumers, on average, would pay a premium for the non-GE version of the product while some would be willing to purchase GE foods without a premium (Lin et al., 2006). Bukenya and Wright (2007) found that younger consumers were willing to pay a premium for GE versions of the product.

More research is beginning to focus on second-generation attributes. Many of the currently marketed varieties of GE foods come from crops that have been engineered to decrease yield losses to pests and/or reduce costs of production (first generation). Second-generation attributes refer to genetically engineered characteristics of the foods themselves, such as extra vitamins that might make the food more attractive to consumers. Lusk et al. (2005) examined the literature up until 2005 and found that benefits to the consumer were significant in explaining the size of the premium consumers would pay for a non-GE food. Huffman (2010) found that U.S. consumers were willing to pay a premium for vitamin-enhanced GE food, as did Lusk (2003). Gonzalez et al. (2009) and Anand et al. (2007) found the same thing for consumers in Brazil and India. With an online survey of German consumers, Hartl and Herrmann (2009) found that GE enhancement of the Omega-3 content of foods or the addition of cholesterol-fighting compounds reduced the discount that GE foods had to offer relative to non-GE products. Boccaletti and Moro (2000) found that a sample of Italian consumers were willing to pay more for GE foods with improved nutritional qualities and lower pesticide use.

A new area of research has been the contrast between intragenic and transgenic goods. Intragenic goods are created by transferring genes from a plant of the same species, but of a different variety, as opposed to transferring a gene from another species or type of plant. Huffman (2010), using experimental auctions, found that consumers discounted GE foods, but were willing to pay a premium for intragenic foods that had enhanced vitamin content versus a plain-labeled product. The difference between the premia for intragenic- and transgenic-enhanced vitamins, however, was not statistically significant unless pro-biotech information was given to consumers. A survey of stakeholders in the potato industry (Toevs et al., 2011) found that certain categories of stakeholders (women, Canadians) were optimistic about intragenic potato varieties. More research remains to be done to determine whether consumers as a whole will find intragenic foods more acceptable than transgenic foods.

Effect of Information on the Desire of Consumers To Purchase GE Foods

Several studies have also considered the impact of information on the desire of consumers to purchase GE foods, and the results have varied. Huffman (2010), Huffman et al. (2007), Hu et al. (2006), and Tegene et al. (2003) found that positive information regarding biotechnology increased the willingness-to-pay for GE foods, while negative information reduced it. Onyango et al. (2004) found that those given both positive and negative information were less willing to buy GE foods than those given only positive information. Martinez-Poveda et al. (2009) found that previous knowledge of GE technology reduces the effects of negative information on the perception of GE foods, but could increase concern for health. Boccaletti and Moro (2000) found that previous knowledge increased the willingness-to-pay for positive GE attributes, while Lusk (2003) found that lack of previous knowledge increased willingness-to-pay.

Other studies have found that consumers value certain types of information. Hu et al. (2009) argued that those choosing to access information about GE foods may be different types of consumers than those who don't access information about GE foods. They found that consumers who voluntarily access *general* information on GE foods are more likely to buy them, while those who access *environmental* information related to GE foods are less likely to buy them. Rousu and Lusk (2009) found that providing consumers with information on the environment was more likely to change consumer purchasing behavior with respect to GE foods, while information on the beneficial impact of GE foods in developing countries created more value for the consumer.

Evidence From Retail Settings

Market settings offer examples of retailers' efforts to consider consumer preferences for GE foods. Some retailers do not have policies that explicitly address GE foods. Other retailers, mostly in the EU, have explicit policies stating that GE ingredients will not be used in their brand name food products.[39] Some companies have even introduced lines of meat and eggs from animals not fed on GE feed (Agriculture and Agri-food Canada, 2007; ASDA, 2011; Carrefour, 2011b; ECCC, 2008; Tesco, 2011; SHAFE, 2011).

Lusk et al. (2005) found that consumers in Europe were willing to pay more for non-GE foods than consumers in other regions. Thus, we might expect to see more responsiveness on the part of European retailers, and indeed some of them have developed auditing procedures for their suppliers (Tesco, 2011). Store visits by researchers in 10 EU countries found few (between 1 and 27) products with GE ingredients in grocery stores in 7 of the countries (King's College, 2008). The results of Mather et al. (2011) suggest that there may be circumstances under which consumers in a few EU countries would purchase GE foods.

A market exists for non-GE products in the United States, as some U.S. retailers do offer non-GE products, and U.S. consumers wishing to avoid GE ingredients may also purchase organic products. However, the share of this market in the United States is still small compared to the widespread marketing of non-GE goods in the EU. For example, the four largest retail chains in the UK[40] all indicate on their websites that their own-brand products do not include biotech ingredients (Tesco website, 2011; ASDA website, 2011; Sainsbury's website, 2013; Wm Morrison website, 2013). They also have tried developing brands of meat from animals fed non-GE feed, but some of the chains have been unable to source enough feed to maintain production (Tesco Food News, 2013; Wm Morrison website, 2013). In contrast, of the four largest U.S. grocery retail chains,[41] two make no mention of GE foods on their websites or corporate responsibility reports, one indicates that non-GE ingredients are not yet defined, and one will make one of its inhouse product lines non-GE in the coming year (Walmart, 2013a; Walmart, 2013b; Kroger, 2013a, Kroger, 2013b; Publix website, 2013; Safeway/Vons website, 2013). Thus, U.S. supermarkets do not perceive the same advantage from marketing non-GE goods that the UK retailers do.

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[39]The supermarket chain Whole Foods has announced a labeling policy that will be implemented by 2018 to indicate if their products contain GE ingredients (http://media.wholefoodsmarket.com/news/whole-foods-market-commits-to-full-gmo-transparency). ERS researchers discuss the economic issues related to food labeling, including GE foods (Golan et al., 2001).

[40]Tesco, ASDA, Sainsbury's, and William Morrison.

[41]WalMart, Kroger, Safeway, and Publix.

Further evidence comes from new product introductions in the United States. Of the 7,637 new food or food supplement products introduced between February 12, 2010, and February 11, 2011, as documented by the Datamonitor database, 2.6 percent advertise[42] that they do not include GE ingredients, 8 percent advertise that they are organic, and another 2.8 percent indicate that they at least have some organic or non-GE ingredients (Datamonitor, 2010-2011). Organic acreage of corn and soy, two potential sources of verified non-GE ingredients for U.S. food producers, remain a small share of the total acreage, with organic soy constituting 0.17 percent of total U.S. production and organic corn constituting 0.26 percent of total U.S. production in 2011 (USDA-ERS, 2013).

Whether patterns of consumer approval have changed over time is not clear. International Food Information Council (FIC) polls seem to indicate that the percentage with favorable opinions of GE foods in the United States fell between 2003 and 2008, but it has recently risen somewhat. In terms of the more rigorous studies cited in this report, even in the United States and in the United Kingdom, for which we cite several studies from different time periods, the temporal patterns are not clear enough to draw definite conclusions.

[42]Via labels or promotional material. The current website was sometimes consulted if the claim was ambiguous.

Conclusion

A large majority of U.S. farmers have adopted GE seeds for corn, soybeans, and cotton since their commercial introduction over 15 years ago. Despite the higher prices of GE seeds compared to conventional seed, farmers realize economic benefits from growing GE crops through higher crop yields, and/or lower pesticide costs, and management time savings.

Farmers will continue to use GE seeds as long as these seeds benefit them. However, it is not clear that first-generation GE seeds will benefit farmers indefinitely. With the help of refuges, the emergence of insect resistance to Bt crops has been low and of little economic significance over the first 15 years, but there are some indications that insect resistance is developing to some Bt traits in some areas and resistance to the herbicide glyphosate has already evolved in certain weed populations. Best management practices can help delay the evolution of resistance and sustain the efficacy of HT crops.

An important issue beyond the scope of this report is the coexistence of crop production systems. According to the USDA Advisory Committee on Biotechnology and 21st Century Agriculture—AC21 (2012), coexistence is defined as the "concurrent cultivation of crops produced through diverse agricultural systems including traditionally produced, organic, identity preserved, and genetically engineered crops." USDA supports all these crop production systems and wants each to be "as successful as possible providing products to markets in the United States and abroad."[43] ERS is collecting data and conducting a study on several aspects of the economics of coexistence of organic, non-GE, and GE crops.

[43]http://www.aphis.usda.gov/newsroom/2013/09/ac21.shtml)

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